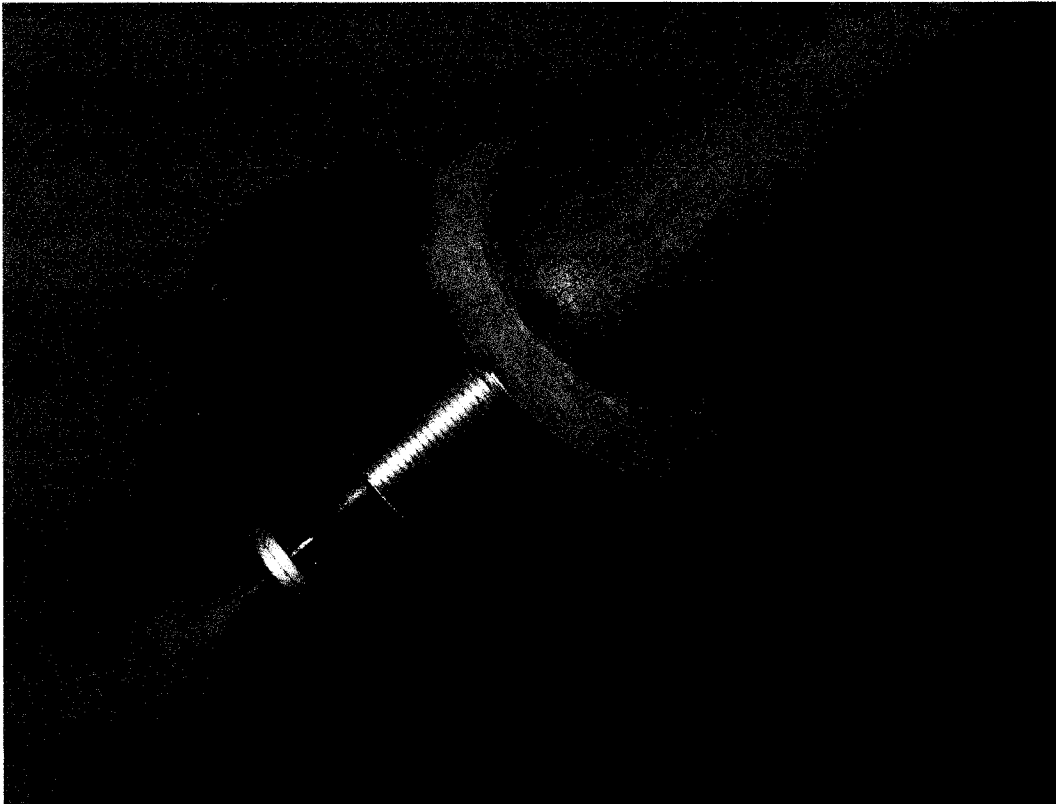


## 5.5 Shielded Room Issues

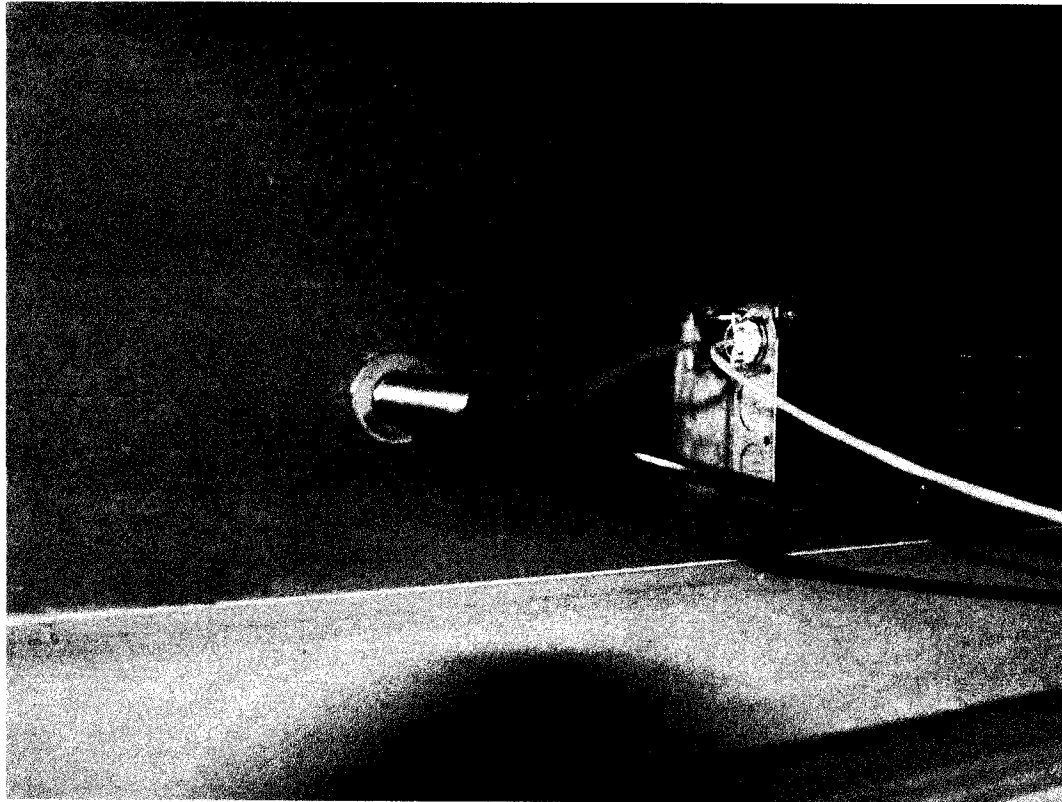
Shielded rooms are often used to isolate sources of EMI from nearby antennas and signal-distribution components. A properly designed and installed shielded room can be an effective means of controlling EMI problems when extreme measures are needed, but with time and modifications many become ineffective shields.

A few common examples of problems with shielded rooms are shown in this section. The technical details associated with the use of small and large shielded spaces are presented in more detail in Section 7. Figure 18 shows where a water pipe penetrated a wall of a shielded room. This pipe can conduct EMI current and voltage from outside sources into the room, and it can conduct EMI current and voltage from sources in the room to locations outside the room. The outside surface of the water pipe should be electrically connected to both sides of the shielded-room wall. This provides a low-impedance path for EMI current to flow back to its source rather than into or out of the shielded room.



**Figure 18** Water Pipe Penetrating a Shielded Room

Figure 19 shows another penetration of a shielded room. In this case a coaxial cable associated with the site's security system penetrated the shielded room. Its shield carried EMI current and voltage into and out of the shielded room. This kind of conducting penetration must be avoided since a single such penetration as shown can completely destroy the effectiveness of a shielded room. In this case a standard coaxial bulkhead connector at the penetration point would have provided a satisfactory means of terminating the cable shield on both sides of the wall of the shielded room.



**Figure 19    Coaxial Cable Penetration of a Shielded Room**

Of interest is that other similar penetration tubes have been found that carry non-conducting fiber-optic cables into and out of shielded rooms. Such penetrations are acceptable since non-conducting cable can not conduct EMI current or voltage into or out of the room, however some fiber-optic cables are constructed with metallic armor, and these should be treated the same as the shield on coaxial cable.

The use of shielded rooms is recommended only for special needs and for the isolation of major sources of EMI. Most sources of EMI can be sufficiently contained by enclosing the actual source inside an inexpensive commercial metal enclosure along with the control of each penetrating conductor as described later in Section 7.

## 5.6 Power-Conversion Devices

In recent years a wide variety of power-conversion equipment has become available for general use. Most such equipment employs electronic switching techniques to convert electric power from one form to another form. Examples are Uninterruptible Power Supplies (UPS), switching power supplies, and variable-frequency power sources.

Many power-conversion devices, but not all, are sources of harmful levels of EMI current and voltage that is injected onto the NEC green-wire ground, power conductors, other grounds, cable shields, and other conductors of a site. Since the EMI current and voltage generated by these equipments is often impulsive, spectral components of their current and voltage often extend from low-order harmonics of their power source up into the UHF frequencies. Some such devices are designed to limit the flow of EMI current and voltage on external conductors to low levels while many other similar equipment is not so designed.

The Federal Communications Commission (FCC) recognized that many electronic devices and power-conversion equipments generate harmful levels of EMI current and voltage. The FCC's Class A and Class B ratings for acceptable levels of EMI voltage were developed and published several years ago.<sup>8</sup> The FCC Class A rating describes acceptable levels of EMI voltage for devices employed in commercial facilities where relatively high-levels of EMI current and voltage can be tolerated. The FCC Class B rating describes lower levels of EMI voltage for devices that are sold for residential use. Other specifications (such as the MIL standards) exist that describe acceptable levels of EMI voltage and current for various military systems, but they do not always apply to radio-receiving sites.

Unfortunately, no document is presently available that covers the specific radio noise and interference requirements for radio-receiving sites, although the FCC Class B specification is sometimes, but not always, used for the purchase of equipment for such sites with varying degrees of effectiveness. Of concern is that many new electronic devices and systems containing power-conversion devices are designed to Class A standards and are intended only for industrial purposes, but they are frequently installed at receiving sites. Modern air-handling systems, variable-speed electric-motor controllers and large Uninterruptible Power Systems are prime examples.

Figure 20 shows an example of a label added to electronic devices made in the United States that are intended only for use in non-residential locations. Any device containing this or a similar label is almost certain to produce harmful levels of radio interference at a receiving site. Devices with such a label should not be procured for use in and around a receiving site. In addition, any device containing electronic equipment that does not have such a label should not be procured for use at a radio-receiving site unless it has been tested to ensure that it meets the FCC Class B requirements or the EMI current levels provided in Table 1 later in this section.

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<sup>8</sup> See Section 8 for more detail.

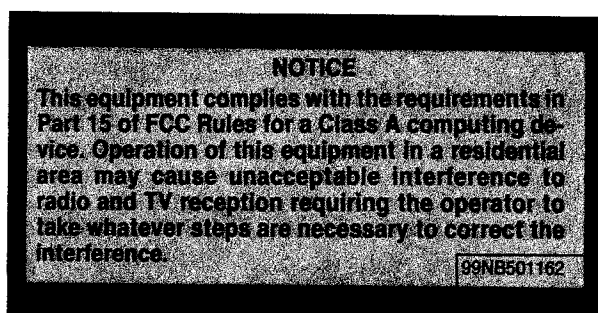


Figure 20 Radio-Interference Label from a Class A Device

Computers, home electronics, and other electronic devices usually have a label indicating that they meet the FCC Class B requirements, or this is stated in their instruction manual. Such devices can be used in a radio-receiving site with little concern that they will generate harmful levels of radio interference although Class B devices should not be used in close proximity to a site's receiving antennas. Be aware that adding external peripheral devices to any item with internal noise sources may cause them to no longer meet the Class B requirements, and thus be an interference source.

The U.S. Navy Signal-to-Noise Program (SNEP) Teams have examined radio-noise and radio-interference problems from both internal and external sources of interference and noise at more than 40 sites at various locations around the globe. Their work consisted of identifying the sources of harmful levels of noise and interference, determining the maximum tolerable levels of EMI current from sources, evaluating the loss of signals from noise and interference, and developing mitigation actions for sources. Extensive measurements have resulted in estimates of the maximum tolerable levels of EMI current at these sites for the reception of low-level signals.

Table 1 provides maximum permissible levels for a small receiving site and a large receiving site. Two frequency ranges were examined. Linear scaling can be used to determine the approximate maximum current for frequencies between the two ranges.

#### LARGE SITE

Frequency Range	Maximum Current
0 to 10 kHz	2 mA
100 kHz to 100 MHz	10 $\mu$ A

#### SMALL SITE

Frequency Range	Maximum Current
0 to 10 kHz	2 mA
100 kHz to 100 MHz	2 $\mu$ A

Table 1 Maximum Permissible Limits for Conducted EMI Current

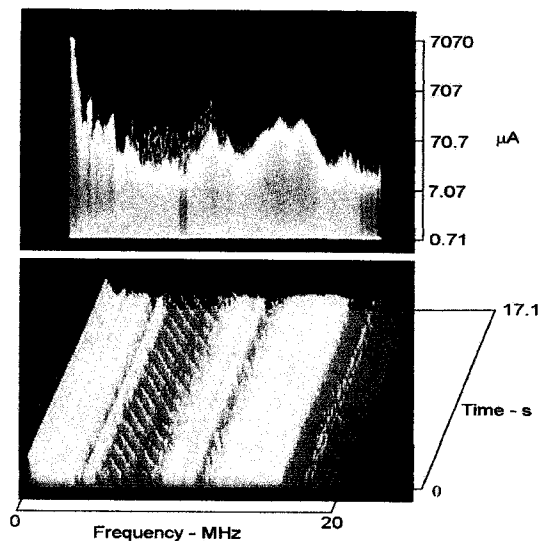
The values of maximum permissible EMI current at frequencies between 100-kHz and 100 MHz are quite low. These low levels were determined from extensive measurements at many receiving sites, and the reasons for the low levels are twofold. The first is that the limits apply to sites that are designed to detect and process low-level

radio signals without harmful radio-interference or added noise above ambient noise levels. The second is that multiple leakage paths can exist for EMI current and voltage to enter the signal paths at all sites, but the permissible leakage level is often determined by only one or two elusive and difficult to identify points of the lowest transfer impedance for EMI current or voltage to enter a signal path. The test equipment needed to identify low-impedance transfer points is seldom available at a receiver site.

Exceptions have been noted to Table 1. Some sites that have nonlinear joints in the antenna system, its counterpoise, or within its signal paths can be susceptible to low levels of EMI current. Sites with power, control, and communications cables underneath its antennas (including buried cables) can be susceptible to low-levels of EMI current flowing on the shields of such cables. Other sites designed with high levels of isolation in signal paths can tolerate somewhat higher levels of EMI current. This indicates that an examination of the properties of low-level radio interference and noise at the input terminals of a receiver is critical, and a determination of its sources is a requisite item in determining the ability of a site to perform as intended.

The maximum EMI current levels in Table 1 are based on the detection of typical signals with a 0-dB signal-to-noise ratio at a receiver bandwidth of 3 kHz. If a site must detect signals at negative signal-to-noise ratios or narrow-band signals with receiver bandwidths less than 3 kHz, the maximum permissible EMI current levels will be even lower than those shown in Table 1.

A few examples of excessive EMI current flowing on cables in a receiving site will demonstrate the problem. Figure 21 shows EMI current flowing on one of the 3-phase output power conductors of a Power Distribution Unit (PDU) over the frequency range of 100 kHz up to 10 MHz. This particular PDU was located within a shielded room that housed the RF-distribution equipment for an HF receiving site. The PDU contained a switching power supply for its electronics along with other digital control devices, and it provided electric power to all equipment located within the shielded room.



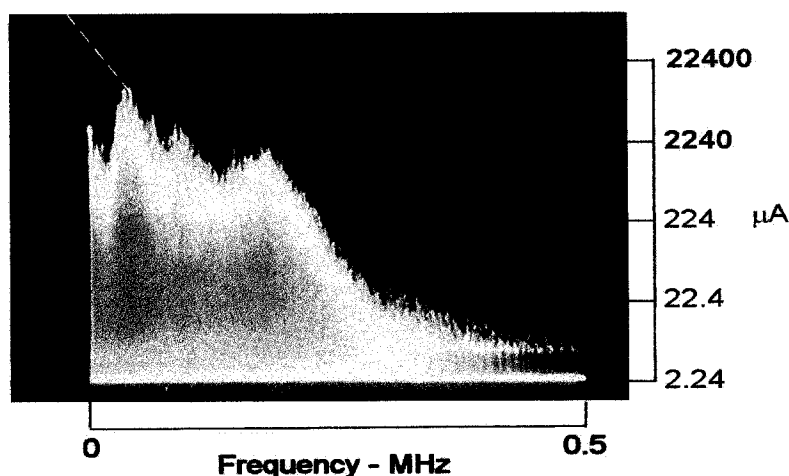
B, 9/10, 051021, 1419, 10, 20, 10, 200, F-70, NF, 20, 0, -30  
PDU, Blue Cable

**Figure 21 EMI Current Flowing on PDU Power Conductor**

Severe peaks and nulls in noise amplitude were found across the entire frequency range of the data at levels significantly above the minimum tolerable level provided in Table 1. The slanting lines in the time-history view over the frequency range of about 3.5 to 8 MHz are from repetitive impulsive noise with a period of 8.3 ms (a pulse occurrence rate of 120 per second). The amplitude of these impulses is shown in the upper amplitude-vs.-frequency view. The noise in the remaining part of the HF band was a combination of impulsive noise at lower levels and closely-spaced spectral components related to harmonics of the power-line frequency and of the switching rate of the power-converter device.

The PDU was examined to determine if it was procured in accordance with the FCC Class B noise voltage rating. No label was found on the unit, a violation of the FCC rules. While the voltage level of noise was not measured in accordance with the FCC test procedures, the high noise current level clearly indicate this unit was either manufactured to the FCC Class A industrial noise requirement or the noise requirement was simply ignored.

Figure 22 shows noise on one of the 3-phase conductors feeding power into the shielded room. In this case the power is provided to a 30-kVA UPS located in an adjacent shielded room, and it passed through a large low-pass filter located on the UPS side of the wall of the shield separating the two rooms. The drop in noise amplitude above about 200 kHz is caused by the filter. Note that the noise level at 500 kHz is very low, and the device met the requirements of Table 1 for a large site at all frequencies above about 1 MHz. The filter installation was effective at the higher frequencies, but excessive levels of noise and harmonic components of the power-line frequency and the switching rate of the UPS exceeded the low-frequency level stated in Table 1.



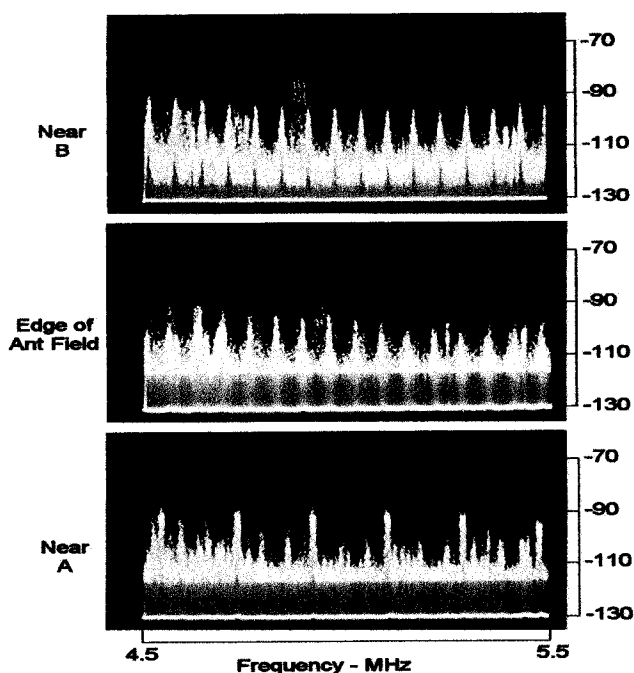
B, 7, 051023, 1145, 0.25, 0.5, 3, 100, F-70, NF, 20, 0, -20  
Blue Cable, UPS J Box in B

Figure 22 UPS Noise after a Filter

The data in Figure 22 shows the difficulty of placing a relatively large UPS adjacent to a room containing radio-frequency distribution equipment. The filters on the power conductors and the use of a ground stud connected to both sides of the wall of the shielded room separating the UPS from the signal paths equipment were effective at the high frequencies of primary interest to the site, but practical filter-design considerations made it impossible to meet the low-frequency requirements.

At this site, electric power for the UPS and other portions of the RF-distribution room was supplied by underground cables that ran under the antenna field at a depth of about 4 feet. Of concern was that EMI current on these cables might be inductively coupled into the counterpoise wires of the monopole antennas at the facility. The concern for this was highlighted by the reception of excessive levels of impulsive noise by the antennas. To check this, a test dipole was placed on the ground in parallel with the counterpoise wires.

Figure 23 shows the amplitude of spectral components of noise collected by the test dipole antenna over the frequency range of 4.5 to 5.5 MHz at three locations. The top location was near the center of the antenna field, the middle location was near the edge of the antenna field, and the bottom location was near a nearby large facility. The data clearly show that excessive spectral components of noise were injected into the test antenna and also into the site's antenna counterpoise wires from EMI current flowing on the underground cables.



LZO, B/BA/A, 051027, 1253/1309/1330, 5, 1, 3, 100, Dipole-0, NF, 20, 0, -30  
Ambient from antenna on gnd at three locations

**Figure 23 Noise from Underground Power Cables**

Multiple sources of noise current carried by the underground power cables were identified including the UPS at the location along with other power-conversion devices in another nearby building associated with air-handling systems, power-conversion devices associated with water-control pumps, another a even larger UPS in an adjacent building, and several additional power-conversion devices operating at lower power levels.

The underground power cables located directly under the antenna field were installed in accordance with the requirements of the NEC, but those requirements were insufficient to ensure the noise-free operation of a radio-receiving site.

An examination of the power-conversion devices contributing to the harmful levels of radio noise in Figures 21, 22 and 23 did not reveal the expected Class B or Class A labels required by the FCC for such devices marketed for general sale. Additional examination and measurements indicated that all were intended for industrial use rather than meeting the FCC Class B requirement for residential use. The use of such devices in and near a radio receiving site can significantly degrade the ability of a site to receive low-level radio signals of special interest, and they should not be installed in such facilities.



## 5.7 Building Issues

Examples of problems found in existing buildings are provided to illustrate the general nature of items that must be avoided to achieve a low-noise radio-receiving capability.

Never install electronic equipment or devices in a receiving site which inject harmful levels of EMI current or voltage into conductors attached to the equipment or device. One way to achieve this is to ensure that all electronic equipment or devices, or any larger system that includes electronic equipment or devices, meets the FCC Class B radio noise and interference requirements or meets the EMI current limits provided in Table 1 on Page 30. Avoid the use of any electronic equipment or device or other system that contains a label similar to that shown in Figure 24<sup>9</sup>. Some items of equipment do not have such a label, but still contain electronic devices. In such cases, the person responsible for the procurement and installation of such equipment must make certain that it complies with the FCC Class B radio-noise and interference requirements and/or the EMI current limits provided in Table 1. There should be no exception to this process. Compliance will ensure that the buildings and facilities of a radio-receiving site will function as planned and as needed to achieve its mission.

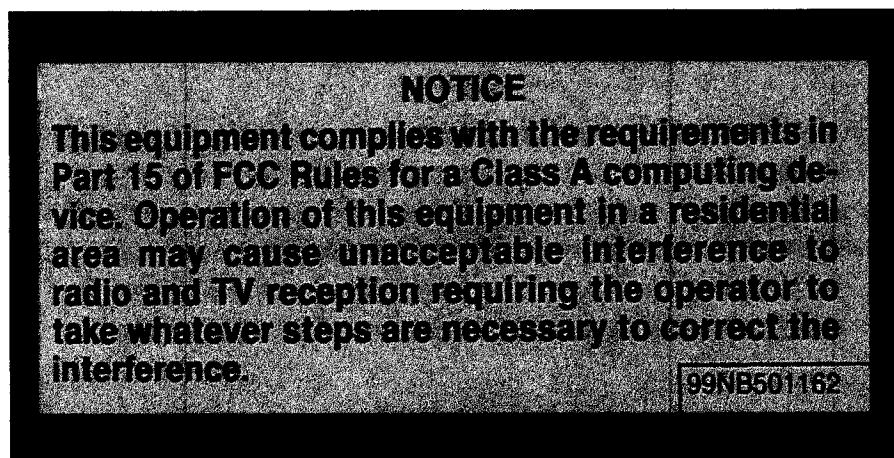
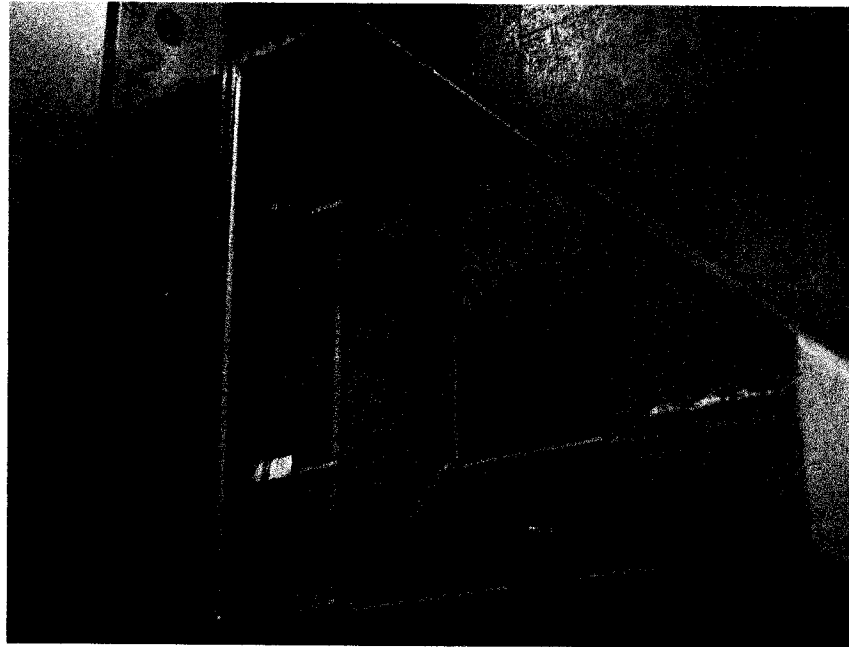


Figure 24 Example of FCC Class A Label

If such a device is essential for the operation of a radio-receiving site, it must be modified in accordance with the principles provided in Section 7 of this document and tested prior to its use. Examples of such potential equipment and devices are Uninterruptible Power Supplies, switching power supplies, recent air-conditioning equipment with electronic controllers, the controllers for variable-speed electric motors, and other similar devices.

<sup>9</sup> This label is used elsewhere in this document. It is reused several times because of the critical need to avoid the installation and use of such equipment or devices in a radio-receiving site unless it has been modified in some way to fully comply with the FCC Class B requirements or the EMI current limits provided in Table 1.

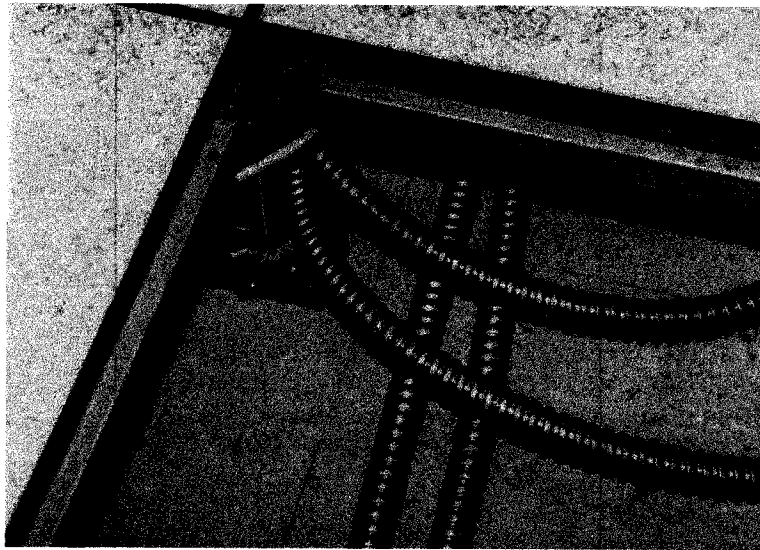
In addition to the above items, other building issues that impact the operation of a radio receiving site can exist. Figure 25 shows a support bracket fabricated out of galvanized steel and bolted to the side of a shielded room. This bracket was welded after galvanizing. While it provided excellent mechanical support, EMI current was flowing on the surface of the shielded room and such current passed through the nonlinear joints of the welds. The resulting harmonics, IM products and IM noise generated by the nonlinear joints added significantly to the RF environment inside the room which contained RF cables, RF preamplifiers and other low-level radio systems.



**Figure 25** Weld on Galvanized Steel inside a Radio-Receiving Building

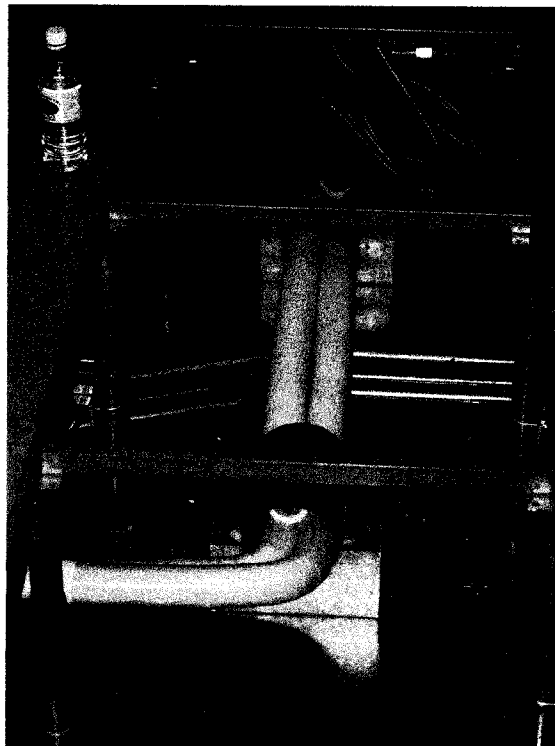
Cable shields, conduits, pipes, and other conductors in a building often carry significant levels of current at harmonics of the electric power frequency and other high-frequency spectral components. Incidental contacts between such conductors and other nearby conductors produce transients of current and voltage that contain high-frequency spectral components, and such transients can cause two problems. The first is undesired intermittent noise in the output of a receiver. Second, such transients have been noted to disrupt the operation of computers and data-processing devices.

Figure 26 shows a photograph of unwanted intermittent contacts. MC cables providing power to electronic devices were in loose contact with each other. Also two of the cables were in intermittent contact with a metal floor stanchion. Unfortunately, the MC cable shields carried significant levels of current at harmonics of the electric power, and a person walking on the floor above can cause sufficient movement to produce harmful levels of transients.



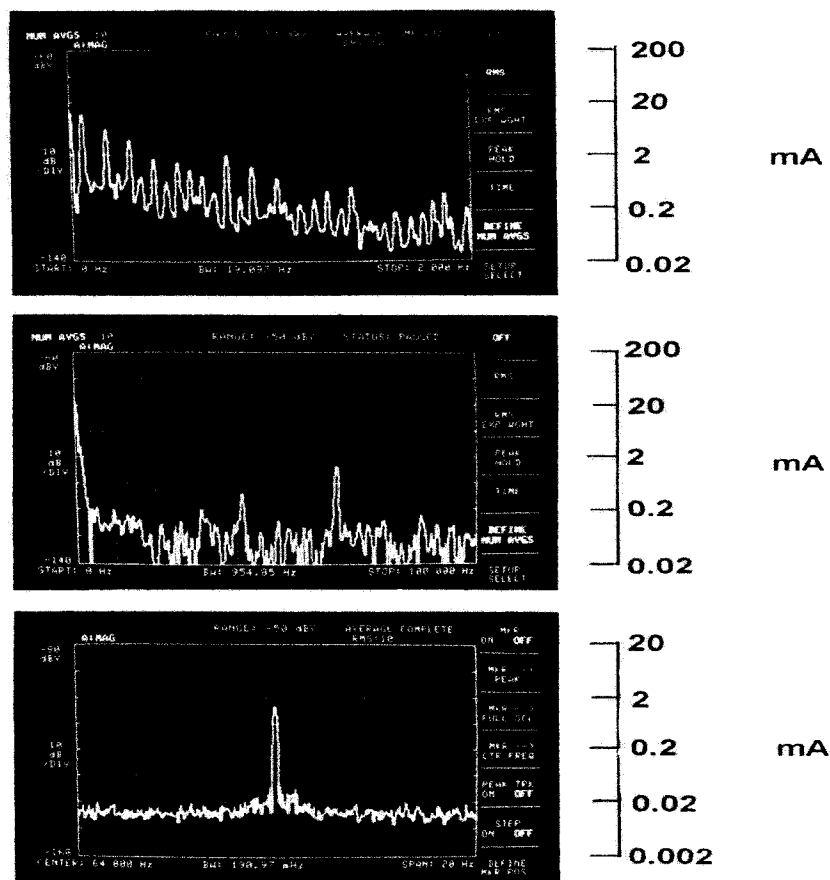
**Figure 26** Incidental Contact, Example 1

Still another example of incidental contacts between conductors is shown in Figure 27. In this case an extra length of MC cable was coiled and left under the floor in loose contact with other conductors. It also resulted in unwanted transients when anyone walked on the floor above the cable. Of interest is that the photograph shows that other metal objects were properly bonded together to avoid the production of transients.



**Figure 27** Incidental Contact, Example 2

Significant levels of low-frequency current at the fundamental and harmonics of the electric-power frequency and at higher frequencies are found on ground buses, conduits, and other conductors of a building. Figure 28 shows three views of spectral components of current flowing on a green-wire ground from a cabinet containing digital devices. The top view shows current at the fundamental frequency and at harmonics over the frequency range of 0 to 2000 Hz. The middle view shows a coarse view of components over the frequency range of 0 to 100 kHz. The bottom view shows an expanded view of a strong component found at 64 kHz. Other cases have shown that 50- or 60-Hz levels as high as 8 A have been found flowing on conduits along with harmonic levels up to 1 A.

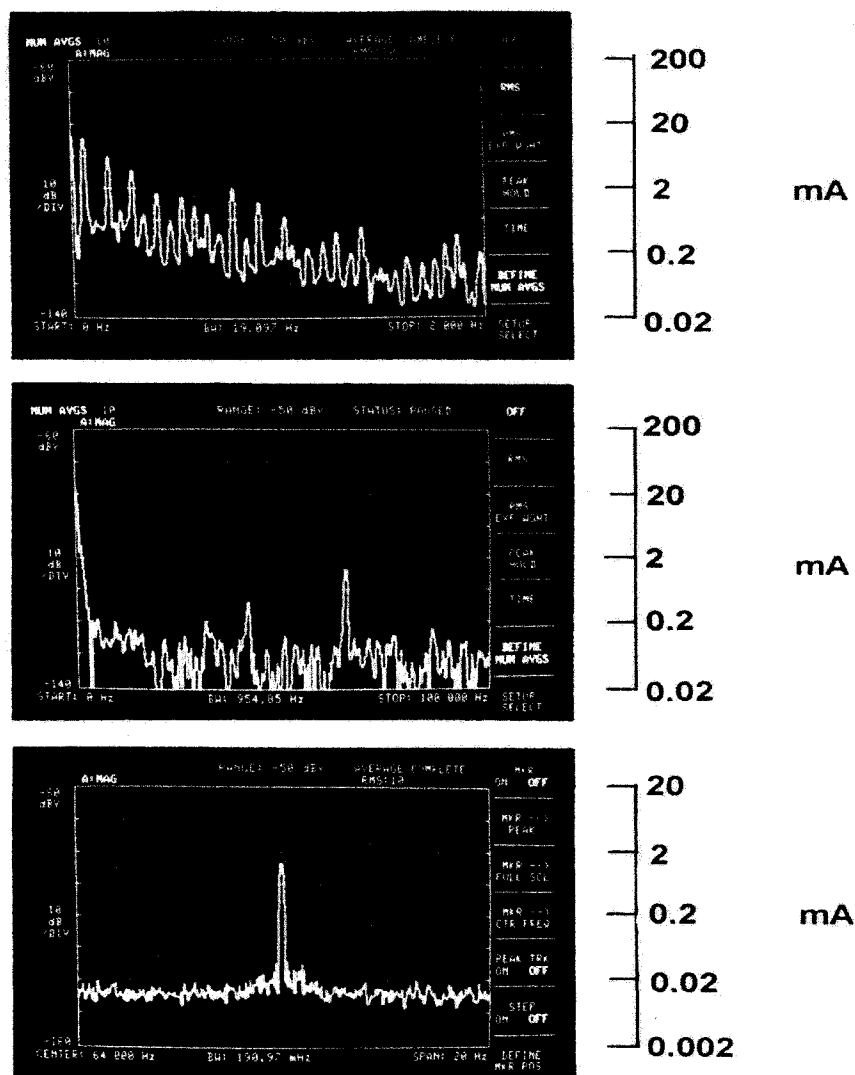


KUN, RM 332, 990212, R408, 1358, CAB GND, CT5 (20/1), P6021 (10mA/mV), 0

**Figure 28** Example of Current Flowing on a Cabinet Ground

The source of the unwanted current levels is usually poorly-designed power supplies and electronic equipment. Unwanted current levels can be avoided by purchasing and installing only well-designed electronic equipment and devices that comply with the FCC Class B noise requirements or the current levels provided in Table 1.

Figure 29 shows another example of unwanted current flowing on a cabinet ground conductor. In this case multiple and sensitive digital signals appeared on a major ground conductor of a data-processing facility. Further investigation identified the same digital signals on several cable shields and on several other ground conductors. The source was a signal cable whose shield was open at one end. This was done to reduce low-frequency current also flowing on the cable shield to harmless levels, but it allowed the high-frequency digital signals to appear on the shield of the signal cable as well as on other nearby conductors.



KUN, RM 332, 990212, R408, 1358, CAB GND, CT5 (20/1), P6021 (10mA/mV), 0.

**Figure 29** Example of Current Flowing on a Ground Conductor

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## 6. STATISTICAL PROPERTIES OF NOISE AND INTERFERENCE

Radio noise and interference at the input terminals of radio receivers can originate from a variety of off-site and on-site sources. Prior to 1998 external sources dominated the noise and interference levels at the input terminals at most HF and VHF receiving sites. Occasional on-site sources would sometimes be found, but they were often lower in amplitude than noise from off-site sources. After about 1998 site-improvement programs started to introduce power-conversion devices into radio-receiving sites. The power-conversion devices convert alternating electric power into other forms of electricity using digital switching techniques. In addition, new and extensive digital signal-processing devices were added to receiving sites at about the same time.

These devices include switching power supplies, variable-speed controls for motors, uninterruptible power sources, and a great variety of digital control and processing equipment. While many such devices were designed such as to limit their emission of noise and interference, others were not. Those that did not generally increased the noise and interference levels at the input terminals of radio receivers, and this limited the ability of a receiver to detect and process data from low-level signals, thus degrading site performance.

Also at about 1998 external power-line sources started to decrease in numbers as electric utilities and base-maintenance facilities started to change insulators on distribution lines within line of sight of receiving antennas from ceramic and glass bells to polymer types as well as updating other aspects of their overhead power lines. Of interest is that higher voltage transmission lines seldom were identified as sources of radio noise since their design, construction techniques and hardware usually met low radio-noise-emission standards.

Unfortunately, the spectral and temporal properties of noise and interference from both off-site and on-site sources often change significantly with time. Rarely does a single and stable source dominate noise levels at the input terminals of a receiver. Multiple simultaneous sources often exist. Significant changes in the spectral and temporal properties of each individual source can, and do, occur erratically within seconds, minutes and to a lesser extent hours. This along with the ever-changing impulsive nature of noise and interference make it extremely difficult to describe its properties. Significant changes in the temporal and spectral properties of noise and interference often occur at time intervals comparable to message lengths.

Figure 30 shows an example of erratic noise and interference found over the 1- to 20-MHz portion of the HF band at a receiving site where the data was obtained with a conventional scanning spectrum analyzer. Four sequential scans are shown where the spacing between the first two scans is about 20 seconds, and the spacing between the other examples is only a few seconds. A careful examination of the four examples shows significant differences in detail from one to the next one. The spectral and temporal properties of the noise and interference changed significantly from example to

example, and the changes cannot be understood from such sequential examples. These examples illustrate the difficulty in describing erratic noise and interference with standard instruments.

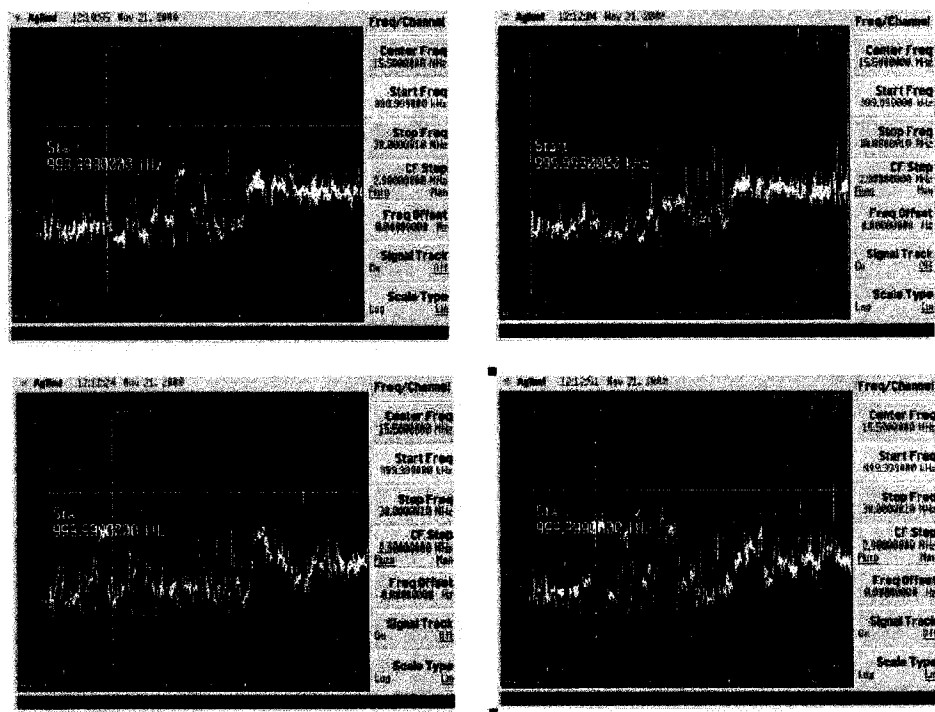


Figure 30 Example of Erratic Noise and Interference

Two additional factors must be considered. The properties of noise and interference are further complicated by the broadband nature of impulsive noise. The amplitude and the spectral and temporal properties of impulsive noise and interference are a function of measurement bandwidth. Conventional electromagnetic compatibility receivers, conventional radio receivers and spectrum analyzers all have measurement bandwidths less than the bandwidth of most cases of impulsive noise. For example, the measurement bandwidth of the noise and interference shown in Figure 30 is a 30-kHz Gaussian-shaped bandwidth. Its amplitude would be less with a measurement bandwidth of 3 kHz, and its temporal structure would be different. Thus, the amplitude, and the temporal properties of all examples of impulsive noise and interference provided in this handbook are dependent on measurement bandwidth. A general scaling rule for amplitude changes with bandwidth is provided in Appendix A.

In addition to the measurement bandwidth issue, the amplitude of noise and interference appearing at the input terminals of a receiver changes significantly across a even a relatively small frequency band. The frequency-flat noise produced by laboratory test sources is seldom encountered at the input terminals of a radio receiver. Significant peaks and nulls in amplitude with frequency are shown in many of the examples provided which illustrates this condition.



Laboratory and acceptance testing of radio receiving equipment and data processing devices is commonly done using time-stable signals and time-stable noise. Both can be measured and quantified with stationary statistical values such as average, root-mean-square, amplitude probability distributions, etc. However, in actual practical cases the noise and interference at the input terminals of a receiver, as well as signals, are often highly erratic, and can only be described as a non-stationary statistical process.

Brief statements for the meaning of stationary and non-stationary data or processes are provided to aid in understanding and defining the properties of noise and interference encountered at the input terminals of a radio receiver.

- Noise and interference data and signals are stationary if their statistical properties (such as average, root-mean-square, amplitude probability, and other measures) are all stable and constant during a time interval of interest.
- Noise and interference data and signals are non-stationary if any of their statistical properties (such as average, root-mean-square, amplitude probability, and other measures) change during a time interval of interest.

Thus, little experience is gained during standard laboratory and acceptance testing of equipment related to its performance under the erratic and changing conditions such as encountered at radio-receiving facilities. Also, there is a major paucity of instrumentation and procedures to cope with the erratic noise, interference and signals encountered at radio-receiving facilities. The lack of attention to this problem also results in a lack of personnel who are trained to understand and cope with practical field conditions.

Unfortunately, the complexity of applying non-stationary statistical processes has discouraged personnel associated with receiving sites from its use. In past years, progress in understanding non-stationary statistical processes has been slow and largely limited to a few mathematicians and specialized statistical individuals. Recently, this has changed because a large variety of cases have been found to fit the definition of a non-stationary process, and considerable attention is now being devoted to such cases. For example, a recent series of conferences at Cambridge University<sup>10</sup> in England dealt with practical communications problems related to the erratic noise and interference encountered at radio-receiving facilities as well as other similar and related problems. A few text books directed at solutions to such practical problems are starting to appear<sup>11</sup> although much additional material related to practical applications is needed.

New applied research programs and additional conferences, such as the University of Cambridge conference, are urgently needed where mathematicians, statisticians and engineers can explore practical problems such as the impact of erratic and non-stationary interference and noise on the reception and processing of erratic and non-stationary radio signals.

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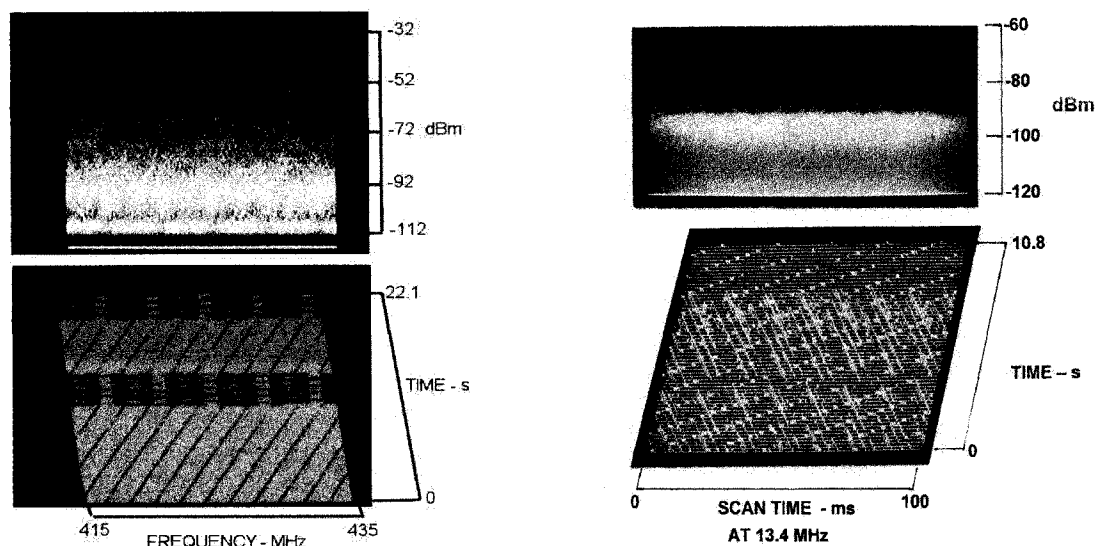
<sup>10</sup> <http://www.newton.ac.uk/reports/9899/nsp.html>

<sup>11</sup> *Nonlinear and Nonstationary Signal Processing*, Edited by W. J. Fitzgerald, University of Cambridge (ISBN-13:9780521800440 | ISBN-10: 0521800447)

Real-time, time-history presentations of signals, noise and interference are used throughout this handbook (and in its complementary handbook for off-site noise sources) to graphically portray the time-changing spectral and temporal properties of noise, interference and signals. This provides an alternate approach to investigate practical field problems and to provide the information needed to identify sources. While this approach offers a convenient graphical way to portray actual conditions, it does not provide a means to supply simple values for noise and interference or the numerical values needed to evaluate the loss of received signals due to noise and interference.

A few additional graphical examples of noise and interference at the input terminals of radio receivers are provided to illustrate the difficulty of defining their properties in simple terms. Figure 31 shows two examples of intermittent interference from the controllers for variable-speed electric-motor drives. The left view shows interference across the 415- to 435-MHz portion of the spectrum of interest at the input terminals of a VHF receiver. The right shows an example of interference at the input terminals of an HF receiver where the spectrum analyzer frequency span was set at zero to better portray the temporal structure of the interference at a specific frequency. In both cases the interference erratically changed with time. Also, significant differences in the temporal structure of the two cases are shown.

In both examples, the interference extended well above and below the frequency ranges shown.



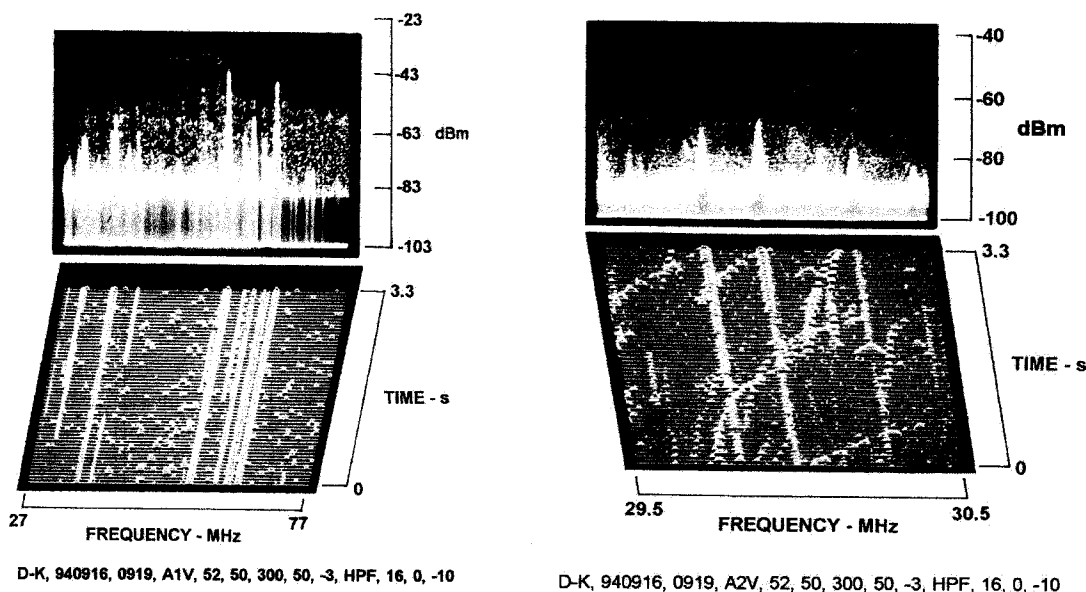
KVHF, 31/32, 080924, 1457, 425, 20, 10, 100, A1-V, 110-700, 22, 0, -20

LZO, 010224, 1157, 13.4, 0, 10, 100, BPF(13.75-15.05), 20, 0, -20

**Figure 31 Severe Radio Interference from Variable-Speed Electric-Motor Drives**

Figure 32 shows two examples of intermittent interference to receivers. The left view shows interference from three frequency-hopping sources located off-site but less than a km from the receiving site. A number of ambient signals are shown as well as the frequency-hopping emissions. In this case, interference to signal reception only occurred when a hopping signal burst was within or near the bandwidth of a VHF receiver, thus the occurrence of interference was erratic and unpredictable.

The right view shows variable-frequency emissions causing intermittent interference to an HF receiver. In this case, multiple emissions from the radio-frequency heaters of multiple plastic molding machines caused the intermittent interference. Such emissions are permitted for the Industrial, Scientific and Medical (ISM) radio service within the band of  $27.120 \text{ MHz} \pm 160 \text{ kHz}$ . The emissions originated from a factory located more than 10 km from the receiving site, and the emissions are clearly outside their allocated frequency band.



**Figure 32 Intermittent Interference from Frequency-Hopping and ISM Emissions**

Radio interference from sources on electric utility distribution lines is frequently encountered at HF and VHF receiving sites. Figure 34 shows two examples of such interference. The left view shows interference from two sources where one operated continuously over the 10.8 s observation time and the other only over the lower half of the time-history view.

The right figure shows the complex temporal structure of two simultaneous sources. In this case the frequency scan of the spectrum analyzer was set at zero-frequency scan and the scan time was changed to enhance the detail of temporal structure. The amplitude differences of the three sources are shown in the upper view. The two views show the details of the interference at the input terminals of a receiver set at a frequency of 30 MHz.

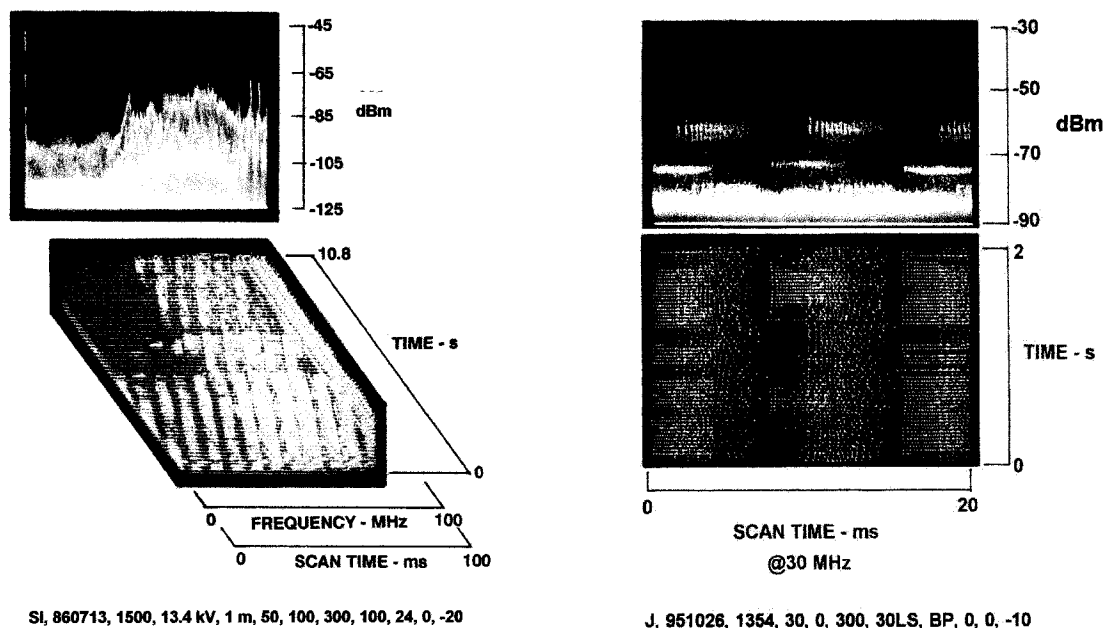
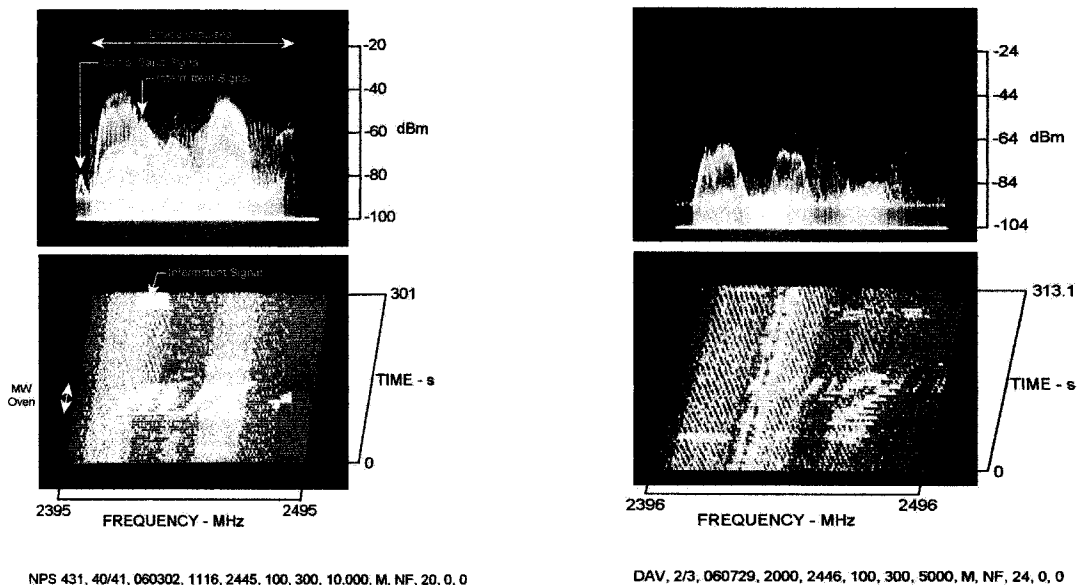


Figure 33 The Complex Structure of Intermittent Power Line Interference

Figure 34 shows two views of signals and interference in the unlicensed 2.4-GHz wireless band. The left view shows the dense population of signals in the band along with an emission from a microwave oven. The upper view shows the densely packed and overlapping signals from multiple 802.11b devices as well as other sources. Interference from a microwave oven is shown about  $\frac{3}{4}$  of the way down the time axis of the time-history view.

The right pair of views shows signals and interference prior to the addition of a wireless router in a home office. The slanting lines are caused by the synchronizing pulses emitted by two fairly strong emissions from existing nearby 802.11b Access Points along with a third low-amplitude 802.11b signal. Strong intermittent interference is shown in the time-history view while the amplitude of each emission is shown in the upper amplitude vs. frequency view. Two narrow-band signals are also shown in the time-history view along with intermittent interference from an unknown source.



**Figure 34 Signals and Interference in the 2.4-GHz Wireless Band**

While emphasis has been given to the erratic structure of noise and interference, the temporal and spectral structure of signals can also be erratic and be statistically non-stationary. Burst signals that occur at random and unknown times are an example.

Figure 35 shows two examples of signals severely distorted by propagation effects. The left view shows an HF signal severely distorted by selective fading where the fading was caused by its arrival from a distant source over multiple ionospheric propagation paths. Four discrete-frequency synchronizing signals can be seen at the upper edge of the time-history view followed by the main band-limited short-duration PSK signal. The strong signal near the left edge of the frequency scale is not related to the signal of interest. The severity of the distortion changed from very little to severe with time.

The example in the right view shows the distortion of a UHF signal caused by the movement of objects in the path between its source and the receiving antenna. In this case the source was a spread-spectrum signal with a spectral width of slightly less than 2 MHz. The spectral sidebands of the signal were suppressed. A narrowband signal exists near the upper frequency limit of the example at slightly higher amplitude than the primary signal of interest.

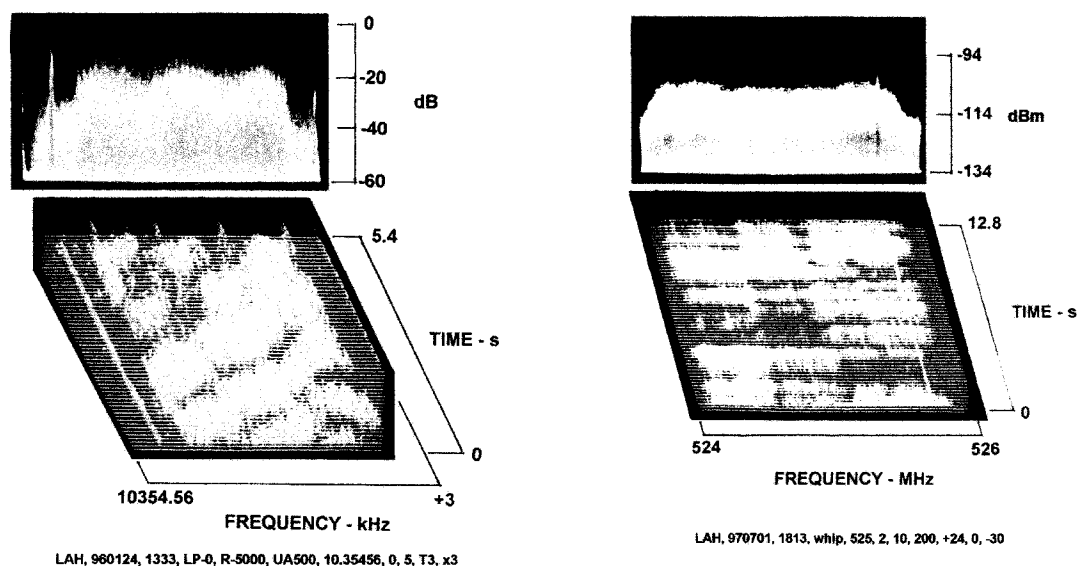


Figure 35 Erratic Signals

## 7. MITIGATION TECHNIQUES

### 7.1 Mitigation Principles

The only effective mitigation technique is to identify each actual source of noise and interference and reduce the emission levels of each source sufficiently to prevent harmful effects.

A large variety of power-conversion devices and other sources are used in modern radio-receiving sites. Examples are switching power supplies, variable-speed drives for the electric motors in air-handling and air-conditioning systems, temperature control devices, Uninterruptible Power Supplies, water-flow control equipment, and many other devices and systems. These devices and systems are highly useful, and they usually add significant capabilities to the operation of a receiving site. Some of these devices are sufficiently noise quiet that their use is acceptable and desirable. Others have been found to be major sources of radio noise, and their use in a radio-receiving site is not acceptable. The rule is: never install a power-conversion device or any other noise or interference source in a receiving site that is, or will become, a source of harmful levels of radio noise.

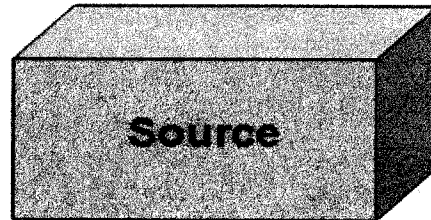
In general, devices and equipment purchased which meets the FCC Class B radio-noise requirements will function in a satisfactory manner in a radio-receiving site. Nevertheless, some such devices installed in a critical location may still cause low-levels of radio noise and interference. A more appropriate set of guidelines is provided in Table 1. Once a device that generates harmful levels of radio noise and interference is installed in a receiving site, the only option is to remove the offending device or implement effective mitigation procedures. The basic principles of mitigation of power-conversion devices and other sources are described in this section followed by other sections containing specific examples of unsuccessful and successful installations.

The techniques described in this section are not new. They were developed and successfully applied to radio noise and interference problems in the very early days of radio. Nanevicz and his colleagues reviewed these techniques in the 1980s and used the term "Topological Control" to describe the EMI control techniques<sup>12</sup>. Later, the students and staff of the Signal Enhancement Laboratory of the Naval Postgraduate School expanded on these concepts under the name "Barrier, Filter and Ground (BFG)" techniques to mitigate sources of radio noise and interference where the name represents the three primary factors necessary for a successful mitigation process (electromagnetic shields or barriers, filters, and grounds).

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<sup>12</sup> J.E. Nanevicz, *Topological Anomalies in Test Methods*, Paper Presented at the EMP Workshop on Compatible Interference Control Techniques at the 1980 IEEE Electromagnetic Compatibility Symposium in Baltimore MD.

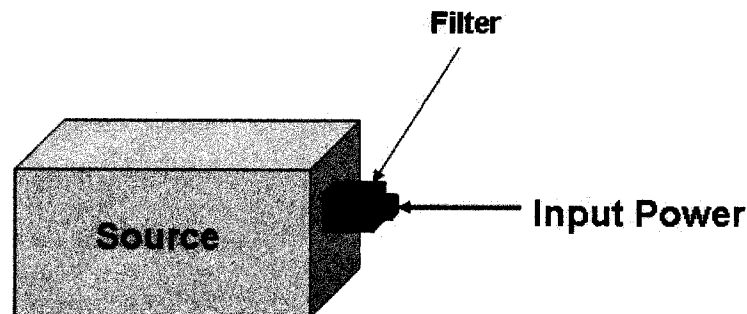
Figure 36 shows the basic aspects of the BFG process where a source is completely enclosed within an electromagnetic barrier. The barrier can be metal such as steel or aluminum. Special materials such as  $\mu$ metal are seldom required to achieve a sufficient level of control. The shield can have electrically small holes such as found in copper screen or punched aluminum material, and standard commercial metal boxes or cases often provide sufficient shielding. Expensive shielded rooms are only required for special cases or physically large systems.



**Figure 36** Source Enclosed within an Electromagnetic Barrier

Figure 36 describes a somewhat impractical case since external sources of electric power usually must be provided to the source, a ground must be provided for compliance with the NEC, the source probably will be connected to other devices, and conductors are often required to control the operation of a source. These items require that conductors penetrate the electromagnetic shield.

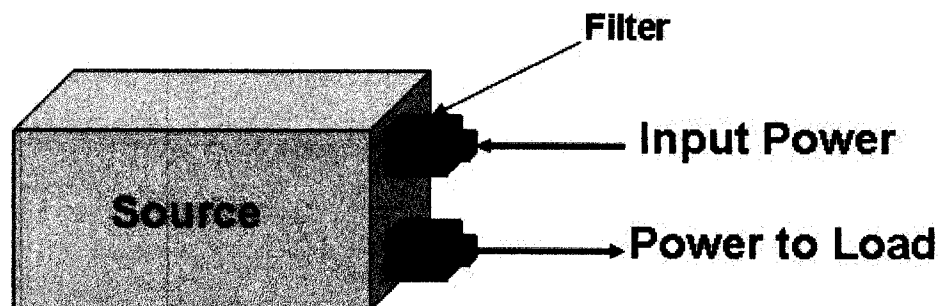
Figure 37 shows how power can be applied to a source. A bulkhead type of filter can be installed directly onto the metallic surface of an enclosure and alternating- or direct-current power can be provided to internal devices through the filter. The filter allows low-frequency electric power to be provided to the source at very low loss while higher-frequency noise is attenuated and cannot be conducted onto the outside power conductors at harmful levels. In addition, the filter prevents external interference and noise from penetrating into the shielded enclosure. Small and inexpensive filters can be used on low-power sources, but large filters will be required for high-power sources. The primary rule is that no conductor can be allowed to penetrate the electromagnetic shield without a filter or other means to prevent the flow of harmful levels of EMI current or voltage to leave or enter the enclosure.



**Figure 37** Provision of Power to a Source

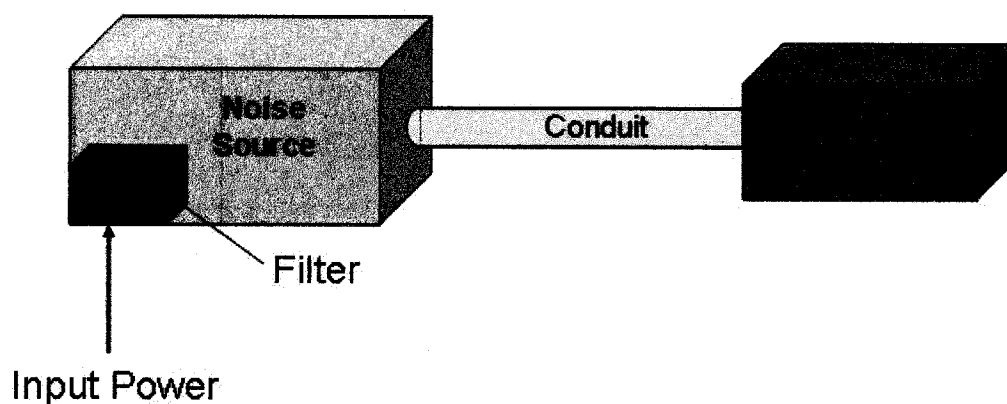


Most sources also must operate or be connected to an external device. For example, many power-conversion devices operate variable-speed induction electric motors by varying the frequency of the power provided to the motor. A second filter can be installed on the surface of the electromagnetic barrier to prevent the conduction of noise current and noise voltage onto conductors leading to external locations or the conduction of noise current and voltage from external sources from entering the enclosure as shown in Figure 38.



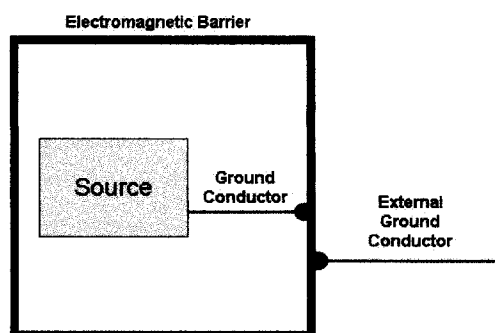
**Figure 38 Provision of Power to a Load**

Alternatively, the electromagnetic barrier can be extended to include the conductors from the barrier to a load. For example, most electric motors are sufficiently enclosed in metal to provide a suitable electromagnetic barrier. Figure 39 shows such a configuration where metal conduit is used between the source and a motor or other load to shield the conductors. The conduit or shield around the conductors must be electrically bonded to both the source barrier and to the barrier enclosing the motor or other load. Open shields cannot be used.



**Figure 39 Source-to-Load Connection**

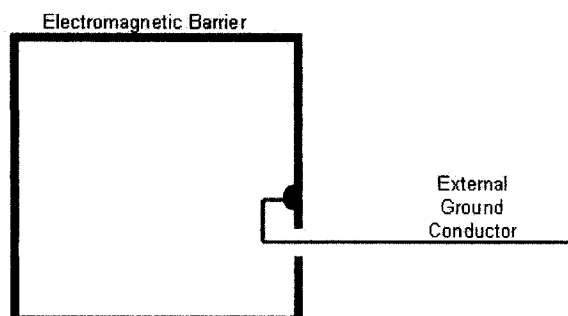
Most electrical and electronic installations require a safety or green-wire ground. Unfortunately, ground conductors often carry significant amounts of high-frequency noise current and voltage (often at higher levels than on the power conductors). Figure 40 shows an effective means to prevent the conduction of high-frequency noise current and voltage from an internal source to an outside conductor over a ground wire or from an external source into the barrier. Ground conductors inside the barrier are bonded to the inside surface of the barrier. Ground conductors outside the barrier are bonded to the outside surface of the barrier. This provides a path for noise current flowing on the internal ground conductor to return to its source inside the barrier. The barrier also prevents the conduction of high-frequency noise current and voltage from external sources into the barrier. Since the barrier will conduct low-frequency power-related current with little loss, all safety aspects of the NEC green-wire ground are maintained.



**Figure 40** Barrier Treatment of a Ground Conductor

As shown in Figure 40, it is advisable to use separate closely-spaced ground connections for the internal and external grounds since unwanted ground current may pass through a single stud.

Figure 41 shows a ground configuration that meets the requirements of the NEC, but it violates BFG principles. In this case the green-wire ground is carried into the interior of the electromagnetic barrier through a hole, and noise and interference current will flow into and out of the barrier. This configuration should never be used for electronic devices in a radio-receiving site.



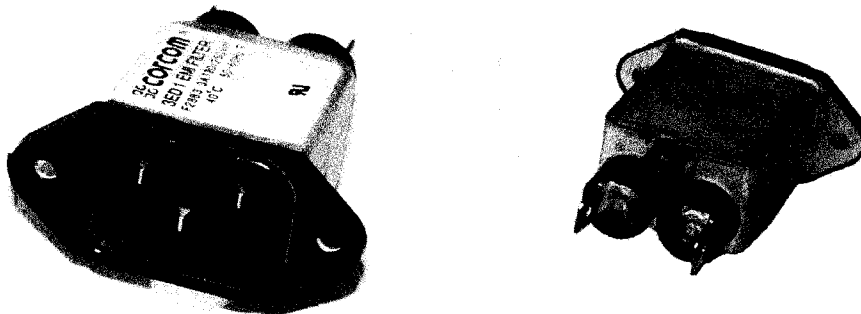
**Figure 41** Improper and Ineffective Treatment of a Ground Conductor

Unfortunately, the method of grounding shown in Figure 41 is frequently used in electronic equipment, and Figure 42 shows two views of a popular type of chassis power connector that fits this case. The ground conductor of the plastic connector protrudes inside a chassis barrier, and it connects to the inside surface of the barrier. The connector meets all requirements of the NEC green-wire ground, but it does not provide a means to control high-frequency noise current or voltage flowing on any conductor. This type of power connector can be used on devices or equipment that does not contain a source of EMI or on equipment that is not susceptible to EMI (such as an incandescent light bulb), but its use in electronic equipment should be strictly avoided.



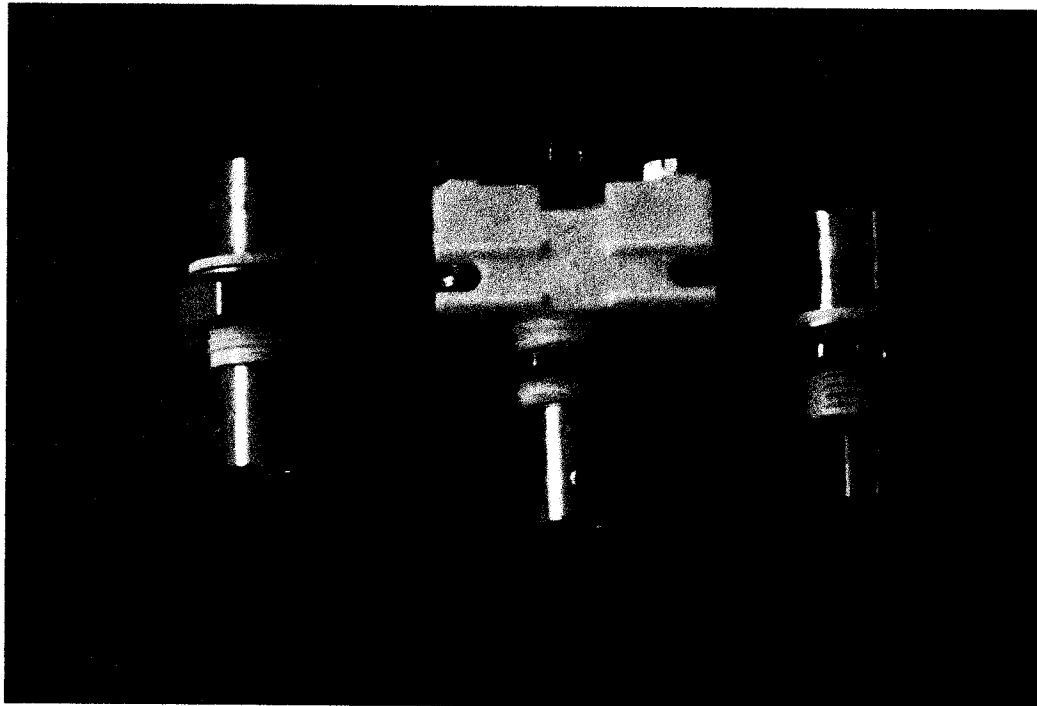
**Figure 42** Chassis Power Connector that does not comply with BFG Needs

Figure 43 shows another popular type of chassis power connector that is available from a number of manufacturers. In this case the connector provides a filter for each power conductor and the ground configuration of the connector meets all BFG requirements. The external ground wire is connected to the external surface of an equipment case or chassis while the internal ground is connected to the internal surface of the equipment case or chassis. While the figure shows a low-power connector, this style is available in a variety of power ratings and filter configurations. It is recommended for use in all electrical and electronic equipment that contains a source of EMI or is susceptible to EMI.



**Figure 43** Chassis Power Connector that meets BFG Needs

Many devices require additional conductors that penetrate an electromagnetic barrier. For example coaxial bulkhead fittings provide a means to interconnect coaxial cables between multiple barriers. However, one must use connector types that comply with the Barrier-Filter-Ground principles. Figure 44 shows three insulated bulkhead coaxial connectors that do not allow the coaxial cable shield to be terminated on each side of a barrier. The use of these types of insulated connectors must be avoided since they destroy the integrity of an electromagnetic barrier. EMI current from a source inside the barrier will be carried outside the barrier on the cable shield. Also, EMI current from outside sources will be carried to victim devices inside a barrier.



**Figure 44** Examples of Insulated Bulkhead Connectors

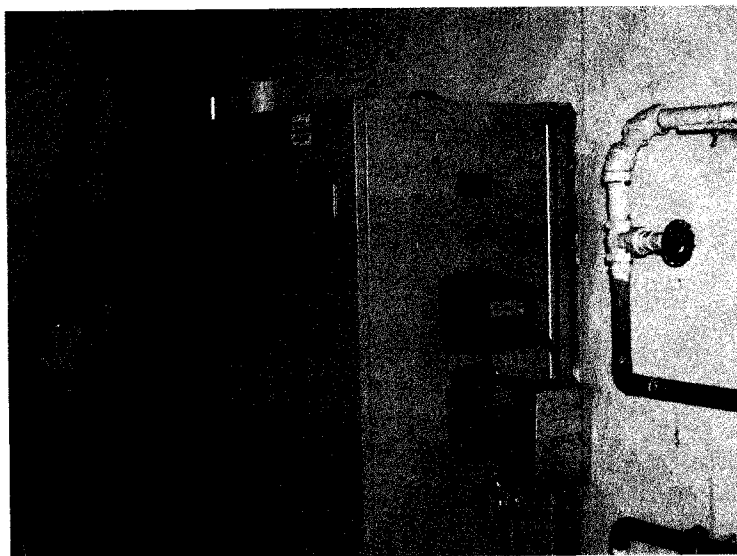
It is important that the processes illustrated in Figures 36 through 44 be strictly followed to eliminate noise problems from power-conversion and other digital devices. Any uncontrolled conductor that is allowed to penetrate a barrier, regardless of its importance, will carry high-frequency noise current outside the barrier where it can be coupled into other nearby cables or conducting material by direct conduction or by inductive and/or capacitive coupling. There is no shortcut to the mitigation process.

## 7.2 Effective Examples

It is impractical in this handbook to provide a specific mitigation example, design or instructions for each of the many sources of radio noise and interference associated with power-conversion and other devices. Successful mitigation actions depend on the physical configuration of the actual source of noise. It must be physically possible to implement the barrier, filter, and ground techniques described in Section 7.1. For example, physically small sources can often be effectively mitigated with minimal alteration to a source and often at low cost. Poorly designed low-power sources of EMI and physically large devices sometimes require considerable modification and at high cost. The general approach is identical to all types of sources, and this section describes actual procedures used to mitigate radio-noise problems.

After a power-conversion source is located and identified, it must be inspected to determine the best approach to limit the transfer of radio noise from the source onto other conductors such as power wires, conduits, ground conductors, cabinet walls and other conductors associated with the operation of the source. The actual source of impulsive current and voltage must be placed inside an electromagnetically shielded enclosure. This can be a small enclosure for a physically small source or it can be a large shielded room for a physically large device.

Figure 45 shows an example of a successful installation of filters on the metal box containing the power-conversion devices for two variable-speed electric-motor drives. In this case two filters were required since the system required both 120-V single-phase and 240-V three-phase electric power. The two filters were bolted directly onto the side of the metal box, and care was taken to ensure that the filter case was in direct electrical contact with the housing. An additional small box was added to each filter to provide physical support for the input power conductors. These two filters prevented noise current and voltage from escaping the metal box over the power conductors and green-wire ground conductor.

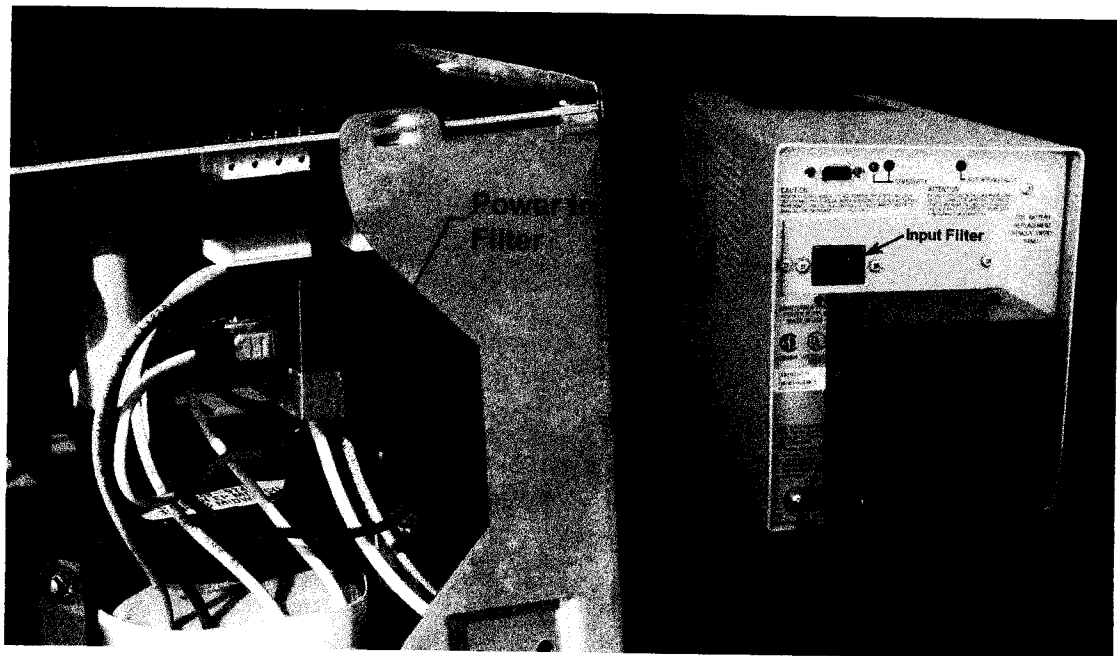


**Figure 45** Filter Installation to Suppress Motor-Controller Noise

Conductors from the controller to two electric motors exited the case on its lower side. These conductors were inside conduits that ran from the controller's case to each motor, and the conduits were bonded to the controller's case and to the motor's housing. Additional conductors associated with an external control box were provided to adjust the speed of each motor, and they also exited the bottom of the controller's case. These conductors were in a flexible shielded cable, and the shield was terminated at the controller's case and at the control-box case. No unshielded conductor was allowed to penetrate the controller's case. All radio noise problems associated with the controller were successfully mitigated.

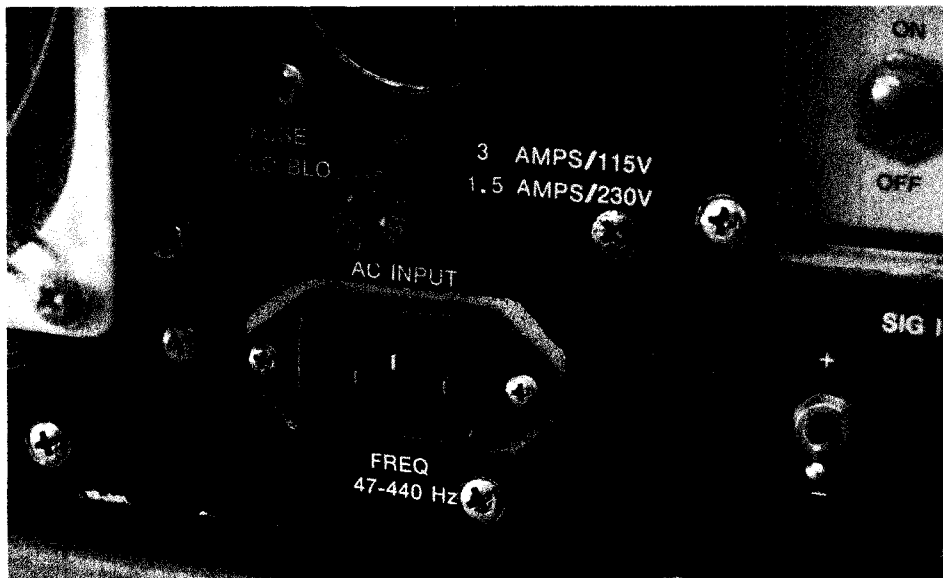
Figure 46 shows two views of a 1.4 KVA UPS that was modified for use in a small receiving site. This particular UPS injected sufficient impulsive noise current onto its power conductors and onto the input and output green-wire grounds that its use in a receiving site prior to modification was unacceptable.

A filter for input 120-V power was added inside the case of the UPS as shown in the left view. There was not sufficient room inside the UPS for the output filter so it was added to the outside of the UPS case and was enclosed in a metal box to protect the short wires from the filter to the electrical sockets. The filter styles and their installation complied with the BFG principles, and the modification to the standard UPS successfully corrected a radio-noise problem.



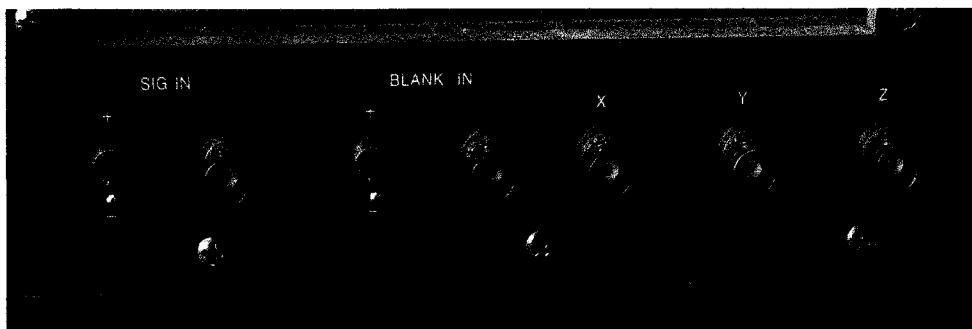
**Figure 46**    UPS Modified to Comply with BFG Principles

Figure 47 shows the rear panel of the Model 7200B Time-History Display described in Appendix A. This instrument contains high-level digital devices and switching power supplies that generate significant levels of impulsive noise, but its case was designed in accordance with the BFG principles described in this section. The power connector shown in the photograph is a small unit containing an integrated filter of the type described in Figure 43. The unit can be operated in close proximity to the antennas of a receiving site without producing detectable noise or interference.



**Figure 47 Power Connector that Complies with BFG Principles**

Figure 48 shows coaxial bulkhead fittings on the rear of the Model 7200B Time-History Display. Five bulkhead fittings were required to pass signals in and out of the unit. Non-insulated bulkhead connectors were used to terminate the shields of coaxial cables on both the inside and the outside of the instrument's case in accordance with BFG principles.



**Figure 48 Coax Feed Bulkhead Connectors that Comply with BFG Principles**

### 7.3 Ineffective Examples

An example of an ineffective filter installation is provided to illustrate some common deficiencies that occur in improperly engineered attempts to solve electromagnetic-noise problems. Figure 49 shows a filter installed to prevent EMI current and voltage from a source from being received by nearby antennas. In this case the source was the electronic controller for a variable-speed fan motor of an air-conditioning unit. The physically-small electronic controller was located inside the large metal housing of the air-conditioner unit. Power to the air-conditioning unit and the variable-speed controller unit was provided through a metal conduit running to a filter located about 15 feet from the air-conditioner unit. Conduit then ran from the filter enclosure to the power panel.

The controller-to-filter conduit was properly terminated on the bottom left side of the filter box. The conduit to the power panel was terminated at the bottom right side of the filter enclosure. The filter was nicely installed in the standard metal housing that provided an excellent and acceptable shield around the filter; however other aspects of the installation completely negated the effectiveness of the filter.



**Figure 49    Improper Filter Configuration**

Several improper aspects of the filter installation resulted in the total lack of suppression of a severe electromagnetic impulsive noise problem. These aspects were:

- The conductors from the controller to the filter carried high levels of impulsive current along with the normal variable-frequency power to operate a fan motor. Some of this impulsive current was inductively and



capacitively coupled to the interior surface of the shield case and was, in turn, inductively and capacitively coupled to the output conductors. There was no electromagnetic isolation or barrier between the input and the output of the filter.

- The green-wire ground conductor also carried high levels of impulsive current and voltage, and the input and output green wires were connected directly together as shown by the green conductor running across the bottom of the case. This provided a direct conducting path for noise current and voltage to bypass the filter. Because the green-wire ground is close to the power conductors, its EMI was inductively and capacitively coupled back onto the power conductors and onto other conductors associated with it in the power panel.
- The physically-small source device was located inside a very large metal enclosure located about 15 feet from the filter. While the conduit from the filter was bonded to the external surface of the large enclosure, electrically long conductors from the source inside the enclosure injected excessive impulsive and broadband noise current into its associated conductors and onto all nearby conductors. The open bottom to this large enclosure and other untreated conductors penetrating the enclosure allowed impulsive noise to appear on the outside of the case and on all associated conduits as well as all power wires and all green-wire ground conductors associated with the large enclosure. This induced noise current and voltage onto the outside surface of the conduit as well as on the power conductors and the green-wire ground conductors running inside the conduit to the filter. These conducting objects constituted a complex, but effective, radiator of the noise. Nearby receiving antennas intercepted the noise fields resulting in high levels of radio interference to all radio receivers at the site.

There is no simple corrective action that can be taken to alter or correct the deficiencies of the filter installation shown in Figure 49. The only viable corrective action was at the source itself. In this case the source device was very small and its enclosure could have been a small and inexpensive metal box along with appropriate filters for all conductors penetrating the small enclosure in accordance with the principles shown in Section 7. These inexpensive and effective mitigation actions required:

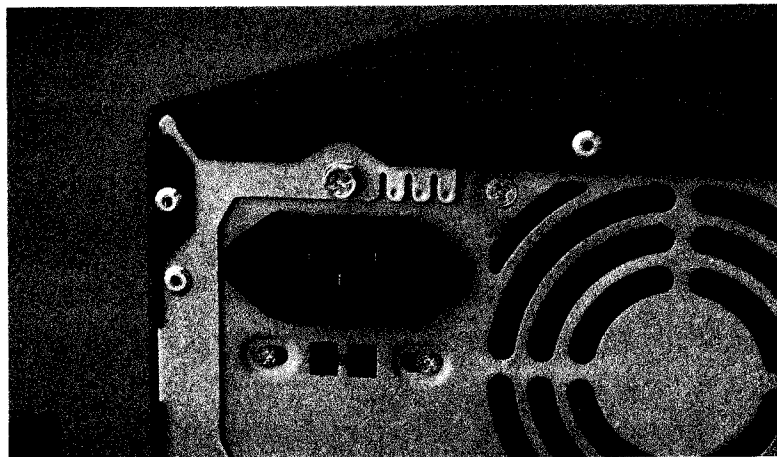
1. The small source device itself must be enclosed in a small metal box.
2. All conductors entering and exiting this metal box must pass through filters with the exception of the green-wire ground which must be terminated on the outside and inside surface of the enclosure.
3. The green-wire ground must be connected as shown in Figure 40.
4. Finally, remove and scrap the existing filter and its enclosure and reconnect all power conductors and their conduits in a normal configuration.

Figure 50 shows another example of a harmful source of impulsive noise. The photograph shows the side panel of a heavy-duty switching power supply. A hole was punched in the panel to provide a means for the DC leads of the power supply to exit its case. In this case, high-frequency components of impulsive noise were present on the direct-current supply conductors, and it created harmful levels of interference to other nearby digital devices and to the reception of radio signals. The corrective action was: add a filter to the DC leads and to the AC input power of the switching power supply.



**Figure 50     Unfiltered Conductors Exiting a Switching Power Supply**

Figure 51 shows a computer power supply with a type of power connector normally considered unacceptable (see Figure 42). However, the internal circuits of the switching power supply in this computer were designed to meet the low-noise emissions requirements of the Federal Communication Commission Class B noise specification, and a label on the computer indicated it had been tested to the Class B specification. In this specific case, the use of the unfiltered connector is acceptable.



**Figure 51     Computer Power Supply not in Accordance with BFG Principles**

## **7.4 Saturated Components in the RF Path**

Examples of the intermodulation products and intermodulation noise created by saturated components in the RF paths of receiving sites are provided in Section 5.2. The following procedures will aid in obtaining and maintaining a noise-free RF distribution system which is free of components which introduce noise and intermodulation.

- Limit the bandwidth of RF paths with band-pass filters located prior to the use of any item whose dynamic range cannot handle the full level of signal, noise and interference power collected by an antenna. Ensure that all band-pass filters can handle the maximum level of signal, noise and interference power received by an antenna including all out-of-band emissions. Filters rated for 1-Watt of total power will usually be sufficient unless a site is located in close proximity to a transmitting site or the site itself contains transmitters.
- Avoid the use of any component in an RF path prior to a band-pass filter that contains elements that can saturate from the total signal power applied to them. This includes items such as line amplifiers, multicouplers, directional couplers and signal splitters. Ensure that all such items are rated to handle the maximum signal, noise, and interference power applied to them. All signal splitters and other components that contain ferrite components or nonlinear capacitors should be able to handle at least 1-Watt of total power and maintain linear operation. Avoid the use of small and inexpensive line amplifiers and multicouplers.
- In general, avoid line amplifier and multicouplers whose amplifying component use less than 12 to 15 watts of d.c. power. In some cases even high dynamic-range line amplifiers and multicouplers will not meet site needs, and site operators must be aware of their adverse impact of signal reception.
- For maximum equipment life, provide sufficient cooling for line amplifiers, multicouplers and other heat generating devices.

## 7.5 Cable Leakage

Examples of signal and noise leakage into coaxial cables are provided in Section 5.3, and Figure 11 in that section provides measured values of cable-to-cable isolation for typical flexible coaxial cables. Note that a 0-dBm signal in a single-shielded cable with only 80 dB of isolation to another similar nearby cable will result in a -80 dBm signal in the second cable. If a receiver connected to the second cable has a noise floor of -130 dBm for a 3-kHz bandwidth, the leakage signal will be 50-dB above the noise floor of the receiver.

The following procedures will eliminate emission leakage problems in RF paths.

- For long coaxial cable runs, use low-loss and solid-shielded coaxial cable such as Times LMR series or Andrew Corporation Helix cable. Carefully check the total attenuation for the length needed from the manufacturer's literature, and use an appropriate size cable.
- Never use single-shielded coaxial cable for any application in a receiving site, even for very short coaxial cables.
- Always use double-shielded coaxial cable. Where flexible cable is needed for short 50-Ohm runs, use a cable such as MI7/84-RG-223/U or one with equivalent shielding.

## 7.6 Shielded Rooms

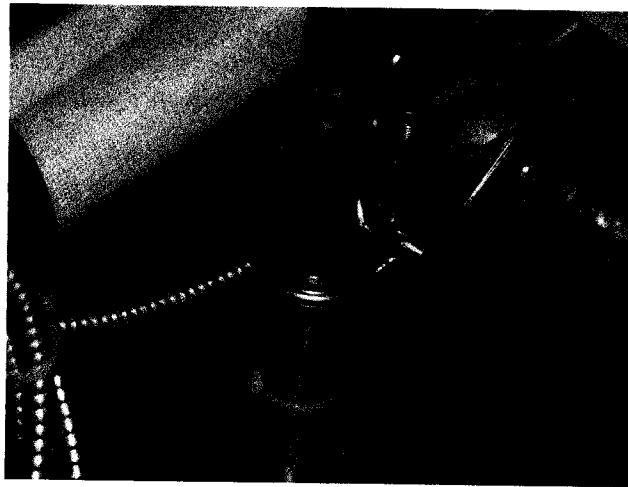
Examples of problems found with shielded rooms are provided in Section 5.5. Additional information about shielded enclosures to control radio interference is provided in Section 6.1.1.

General guidelines for the use of shielded rooms are provided below.

- Shielded rooms are required only for highly critical applications where their cost can be justified. Most sources of radio interference can be controlled and isolated using standard metal enclosures provided the barrier, filter and ground techniques described in this handbook are properly used.
- Never allow a conductor or a pipe to penetrate a shielded room or a shielded enclosure without bonding it to both the external and internal surfaces of the shield wall with electrically-short bonding conductors.
- If a shielded signal cable or a coaxial cable is allowed to penetrate a shielded room or a shielded enclosure, its shield must be terminated on both the inside and the outside surface of the shield wall. Standard non-insulated coaxial feed-through connectors provide an excellent means to terminate a coaxial cable shield to both surfaces.
- Shielded rooms provide excellent attenuation of electric fields from internal and external sources. However, they provide only partial isolation from near-field sources magnetic fields located inside a shielded enclosure at frequencies below about 50 kHz, and near-zone techniques can be used to detect, measure, and receive such sources outside an enclosure. External sources of magnetic fields at frequencies below about 50 kHz also penetrate a shielded enclosure and can be detected inside such an enclosure with near-zone techniques. This is because the skin depth of current flowing in shielded material is often larger than the thickness of the material at low radio frequencies. Thus, caution must be used in locating a shielded room and in its applications.
- The conducting strips around doors deteriorate with use and age thus decreasing the effectiveness of a shielded room. If a full shielded room is required to prevent an internal source from escaping the room or an outside source from entering the room, then ongoing maintenance is necessary.

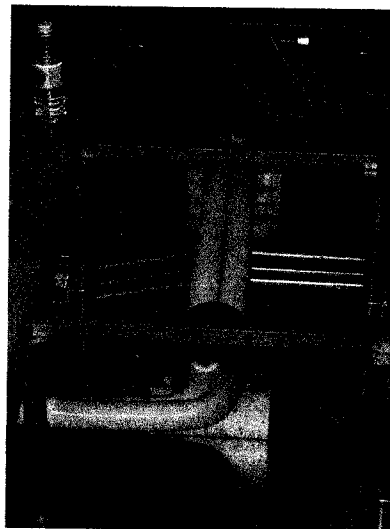
## 7.7 Buildings Issues

A number of building issues have been noted at receiving sites. Among these are numerous cases of incidental contacts, and examples are shown in Figures 52 and 53. For example Figure 52 shows an MC cable touching a floor support and a conduit. If potential differences exist between the cable and the other metal items and movement occurs, the thin layer of oxide on the floor support and on the conduit can be penetrated with a resulting electrical transient. The transient will be propagated along the conducting objects, be inductively and/or capacitively coupled to other conductors and can eventually reach sensitive equipment. Such transients have been observed to disrupt computers and can enter the RF paths to radio receivers.



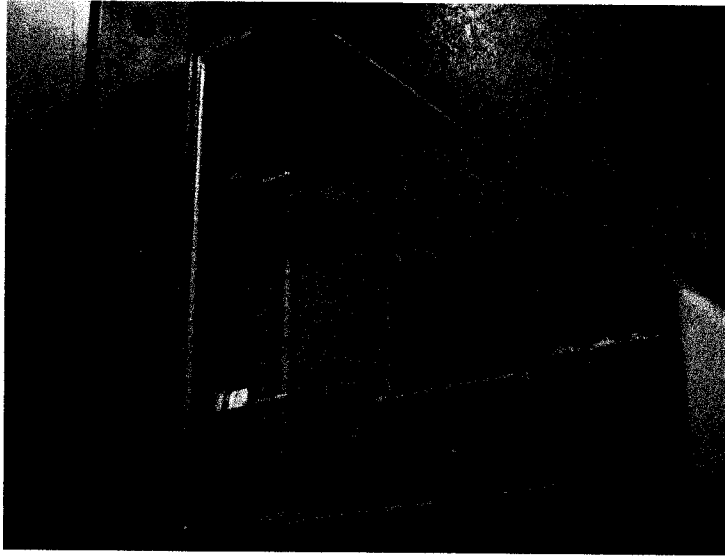
**Figure 52** Incidental Contact, Example 1

Figure 53 shows another example where a loose coil of BX cable touches other metallic items under a raised floor. Other conductors are supported or bonded to avoid incidental contacts.



**Figure 53** Incidental Contact, Example 2

Figure 54 shows an example of a weld on galvanized angle material used to support electrical and electronic equipment. Current flowing in the welded joints can produce intermodulation products and intermodulation noise which is conducted away from the source by the nearby metal conductors. While the welds have been painted, this has no impact on the production of these unwanted products.



**Figure 54     Welds on Galvanized Metal Supports**

## 7.8 Other Site Issues

Many receiving sites contain other buildings for a variety of purposes and uses. Emissions from all electrical and electronic equipment and devices in these buildings must also be sufficiently low that they do not adversely affect the reception of low-level signals. As a general rule, all such devices should be required to meet the Federal Commission (FCC) Class B emission limits described later in Section 8.

Figure 55 shows an example of a site issue that caused harmful levels of radio noise to appear at the input terminals of radio receivers. The security camera shown in the example was powered by a switching power supply that did not meet FCC Class B emission limits and was not modified in accordance with the barrier-filter techniques described in Section 7.1. Radiation from noise current flowing on the camera mount and its associated cables was intercepted by the nearby antennas. In this case the solution was to implement a field modification by replacing the switching power supply with an analog type of power supply.



**Figure 55** Security Camera Powered by a Noisy Switching Power Supply

Sometimes power cables will be buried under an antenna field. In such cases care must be taken to ensure that high-frequency noise-current levels carried by such buried power cables is sufficiently low that inductive and capacitive coupling of harmful levels of noise current into antenna counterpoise systems and/or directly into antenna elements does not occur. A good rule is to limit the high-frequency noise current flowing on such cables to the maximum values provided in Table 1.

Communications cables are sometimes routed under antennas, and in such cases the high-frequency shield current carried by such cables must be limited to the values provided in Table 1.



## **8. SPECIFICATIONS AND STANDARDS**

### **8.1 General Comments**

A large and often confusing variety of standards and handbooks exist which are related to the control of electromagnetic noise and interference. Many of them have portions that can be applied to radio-receiving sites and facilities, but none fully cover the specific needs of such facilities and sites. Most of the existing standards and handbooks have old and out-of-date information that can mislead site planners and operators. Some contain technically inaccurate and incorrect information, especially with regard to grounding.

A comprehensive review of available standards and handbooks as they apply to radio-receiving facilities and sites is badly needed, but it is beyond the scope of this document. This document is limited to the presentation of the technical aspects of noise and interference encountered by its authors over several decades of investigations at receiving sites. A partial listing of these documents is provided in this section.

### **8.2 National Electric Code**

All electrical and grounding aspects of buildings at a receiving facility or site should be required to fully meet the requirements of the National Electric Code (NEC). This includes all aspects of electrical power at a receiving site that supply electricity to equipment. Full compliance with the NEC is required by a DoD directive, and each facility or site should have available the latest edition of the NEC as well as one or more individuals trained in its use.

Of special interest is that while compliance with the NEC is required of all U.S. Department of Defense facilities, the NEC is not a government produced or sponsored document. It is a document produced and provided by the National Fire Protection Association (NFPA) for the protection and safety of personnel, equipment, and buildings from electrically-related causes. The document is updated periodically by the NFPA.

Copies of the NEC can be ordered on-line at nominal cost from the web site for the NFPA at [nfpa.org](http://nfpa.org).

An earlier section (Section 4.3) describes one limitation of the NEC green-wire ground as it applies to radio-receiving and data-processing facilities or sites. The NEC does not include the specific aspects or implications of sources of radio-noise and radio-interference that might be generated by equipment and devices using electric power. The aspects of equipment and devices that are sources of radio-noise and radio-interference are at least partly covered by other standards and handbooks such as the FCC Class B requirements described in the next section and also by this document.

### 8.3 Federal Communications Commission Part 15, Class B

Compliance with the Federal Communications Commission (FCC) Class B<sup>13</sup> noise limits is often required for equipment purchased for use in radio-receiving facilities, and this should be a requirement for all electrical and electronic equipment and devices procured for use in such facilities. The FCC Class B requirement is currently the most practical and most effective reference available for the procurement of low-noise-emission electronic and electrical equipment.

However, the FCC Class B noise requirement has one limitation that must be considered when conducting measurements to ensure that a device is suitable. The Class B noise requirement is based on the measurement of noise-voltage levels, and suitable instruments are available for such measurements from a number of instrument manufacturers. One needs to ensure that the frequency range and measurement bandwidths of such instruments realistically describe noise and interference conditions. However, voltage measurements are valid only at the exact source of a noise or interference where a zero-voltage-reference exists. Unfortunately, sources can inject harmful levels of noise and interference into many source-associated conductors (including ground conductors), and the impedance of even short lengths of any conductor will result in invalid noise and interference voltage reference except at the source. Any noise-voltage measurement made at even a short distance from a source will be suspect and probably will not be valid. Also, all voltage measurements made at a location with multiple sources, no matter where made, will be suspect since a zero-voltage reference will not be present.

While the level of discrete-frequency spectral components of noise can be accurately measured with many instruments, the amplitude of broadband impulsive noise is dependent on the bandwidth of the measuring device. Thus, considerable care must be taken in voltage-measurement procedures of impulsive noise to ensure compliance with the FCC Class B limits. These aspects of noise measurements are discussed further in Appendix A.

Of interest is that current measurements of both discrete-frequency spectral components of noise and interference, and also of broadband cases, can be measured with a broadband current probe. A reference point is not required for current measurements or for multiple sources. All examples of the measurement of noise and interference in this document injected onto conductors are based on current measurements, and Table 1 provides recommended maximum values of noise current generated by equipment for radio-receiving sites.

The FCC Class B measurement procedures need to be updated to include maximum tolerable values of discrete-frequency and broadband noise current, a measurement that is independent of the need for a zero-reference point.

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<sup>13</sup> 47 CFR part 15, Rules and Regulations, Federal Communications Commission, Washington D.C.

Electronic devices and equipment sold for use in a residential installation must be in accordance with FCC Class B requirements and must contain a label indicating its compliance with the requirements. The instruction manuals of all equipment complying with the FCC Class B noise emission standard also contain this information. An example of such a label is provided in Figure 56.

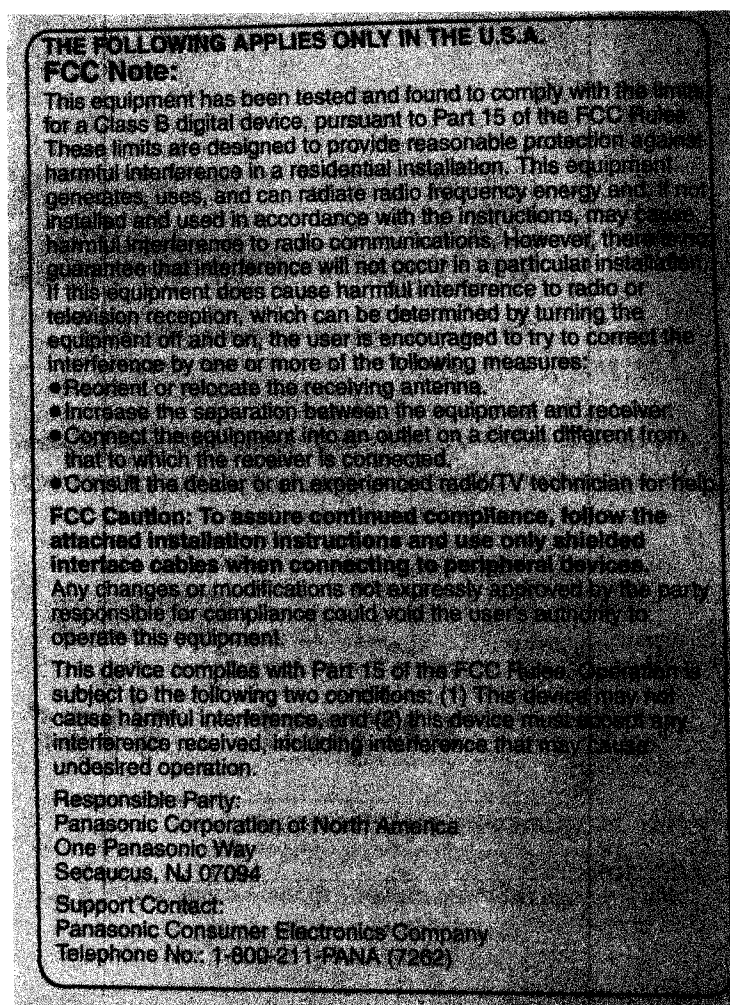


Figure 56 Example of a FCC Class B Label

Electronic and electrical devices rated for the FCC Class A noise and interference requirement must not be tolerated in radio-receiving or data-processing facilities since this requirement allows unacceptable levels of high-frequency noise and interference to be emitted by electrical and electronic devices and be injected into power, ground, and other conductors of a facility. The Class A noise and interference limits are intended only for the procurement of equipment to be used in industrial facilities where high radio-noise levels can be tolerated. Examples of the FCC Class A label required for all electronic devices marked in the United States are provided earlier in Figures 20 and 24.

## 8.4 Coaxial Cable Designations

In the WWII era, coaxial cable was designated as RG- (Radio Guide) followed by one, two, or 3 numerals, and then /U for universal. This system was replaced in 1976 by the new 'revision E' of MIL-C-17 which introduced the M17/ system. Note that cables manufactured after 1976 and bearing only RG/U nomenclature are essentially unregulated and should be avoided. Only M17/ coaxial cables must be manufactured to meet any standard. Cables mentioned in this document by their old designations cross reference to current nomenclature as follows:

<b>Old</b>	<b>Current</b>	<b>Low smoke/halogen</b>
RG8/U	M17/74-RG213	M17/189-0001
RG58/U	M17/28-RG58	M17/183-0001
RG214/U	M17/75-RG214	M17/190-0001
RG223/U	M17/84-RG223	M17/194-0001

## **Appendix A   INSTRUMENTATION**

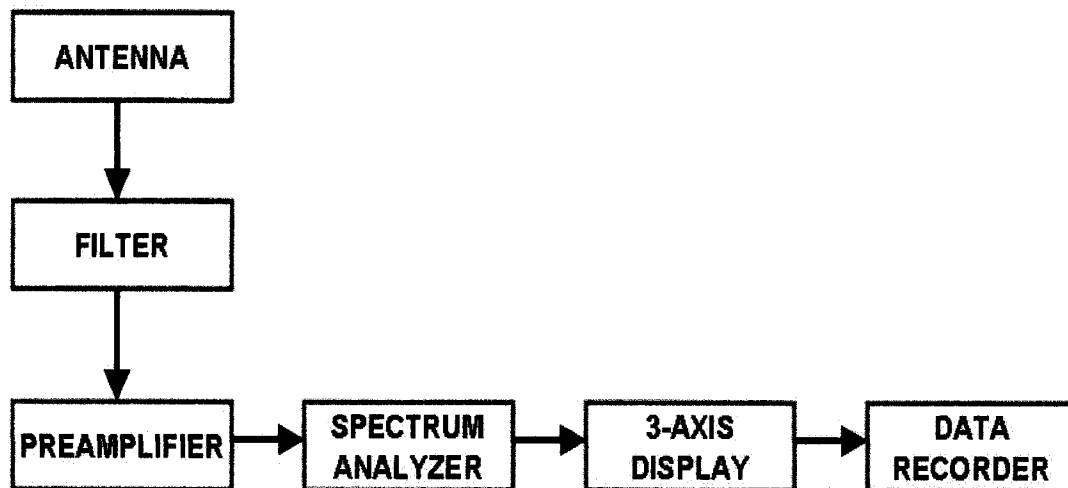
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## ***A.1 Instrumentation for the Definition of Signals, Noise and Interference***

The instrumentation used for field measurements of signals, noise, and interference is described in this appendix. An understanding of both the capabilities and the limitations of the instrumentation is necessary to fully evaluate the implications of the examples of data provided.

The purpose of the instrumentation is to provide a visual presentation of the primary properties of time- and frequency-varying signals, radio noise, and interference in any portion of the radio spectrum. This includes a means to portray both the temporal and spectral structures of signals, radio noise and radio interference in selected bands where the both the frequency span, the time of observation, and other instrumentation parameters can be rapidly changed to best describe the conditions encountered. One further requirement was included. The amplitude, frequency span, and time of observation must be calibrated and presented in commonly accepted engineering terms.

Figure 57 shows a block diagram of the primary components of the instrumentation used for most measurements. The input is usually connected directly to the actual antenna used for signal reception or to a current or voltage probe. This enables the instrumentation to observe the actual signal, noise and interference conditions applied to a receiver or to examine the broadband current and voltage on cables and grounds.



**Figure 57    Block Diagram of the Instrumentation**

Figure 58 is a photograph of a typical instrumentation configuration used to investigate signals and noise appearing at the input of a receiver, signals carried on cable shields and ground conductors, or other uses. The instrumentation is mounted on a wheeled cart to allow moving it to any desired location, and only the primary instrumentation is shown. Auxiliary instrumentation such as filters, probes, and additional preamplifiers are shown in other figures.

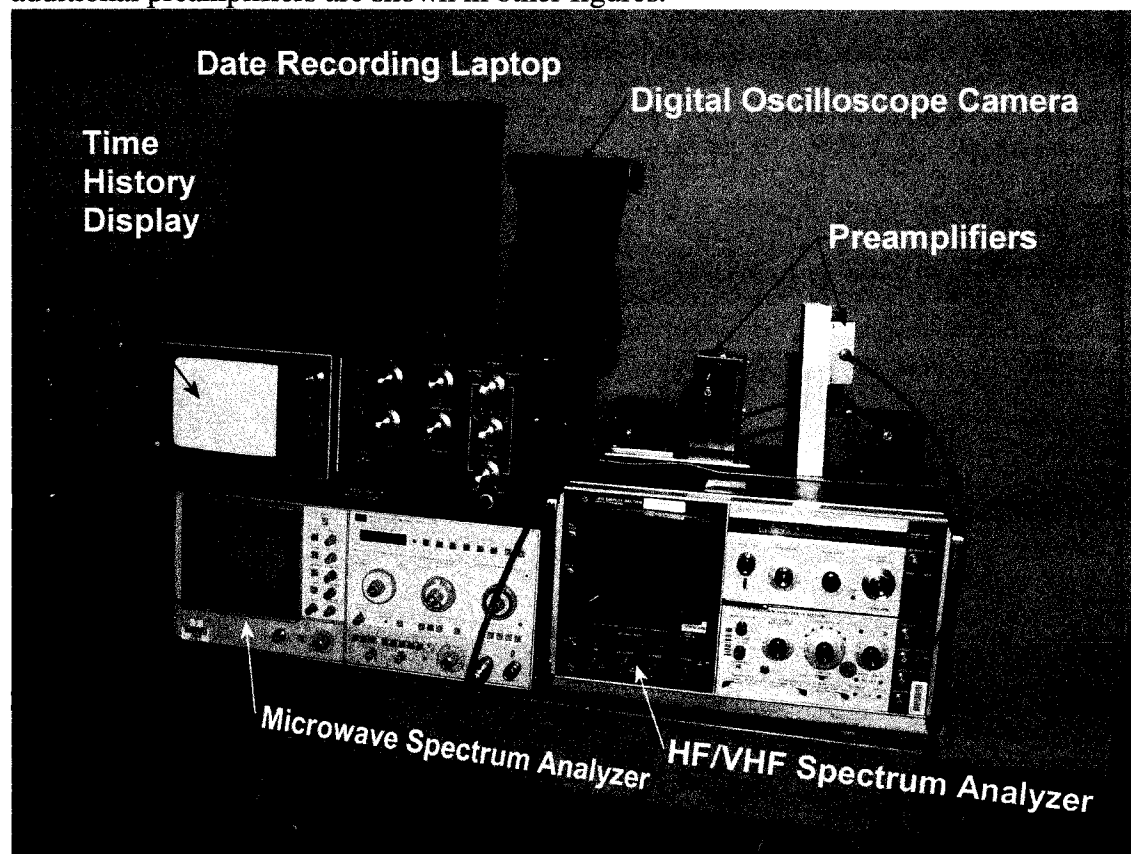


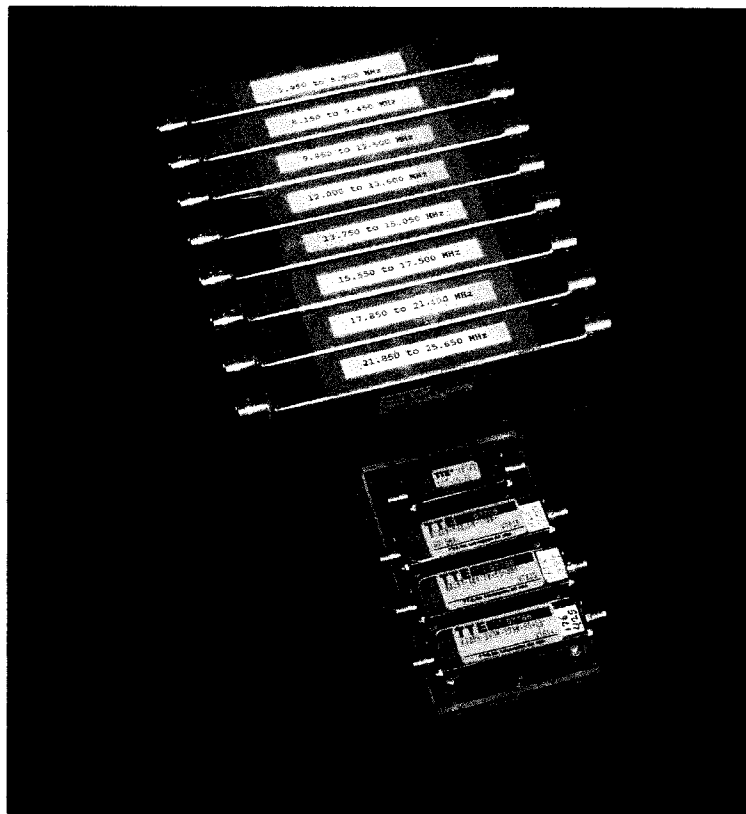
Figure 58 Typical Instrumentation configuration



### A.1.1 Filters

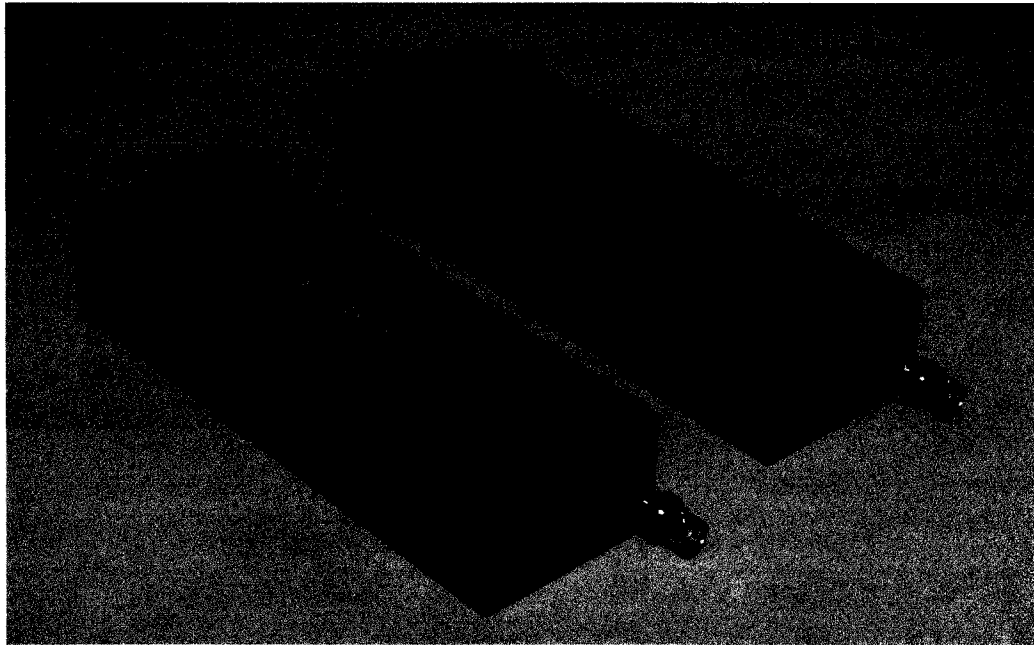
A band-pass filter is provided for each portion of the radio spectrum to be observed. The filters are used to avoid strong out-of-band signals that might cause overloading of the preamplifier and/or the spectrum analyzer. Care was taken in the design of each filter to ensure that its dynamic range was sufficient to avoid saturation of its internal components. Many kinds of small commercially-available filters were found to be unsuitable for the measurement program because of component saturation.

Figure 59 shows a photograph of two sets of filters often used to examine signals, noise and interference in the HF, VHF and the lower part of the UHF bands. The top set consists of a bank of eight filters covering portions of the HF band. This particular set shows band-pass filters covering portions of the HF spectrum between allocations for the International Broadcast Service. The bottom set shows four band-pass filters covering portions of the VHF and UHF bands. A number of additional single filters are used for special measurements.



**Figure 59** Example of Band-pass Filters

Figure 60 shows a photograph of the filters used for measurement in the 915-MHz and the 2.4-GHz bands. These filters are physically large to provide linear operation for the maximum total signal power imposed onto their input terminals.



**Figure 60** Example of Special Purpose Filters for the UHF Band

Many additional special-purpose high-dynamic range filters were designed, fabricated and used for special-purpose measurements in portions of the radio spectrum.